STATE OF NEW YORK

CONSERVATION DEPARTMENT

DIVISION OF WATER POWER AND CONTROL

WATER POWER AND CONTROL COMMISSION

ENGINEERING REPORT

ON THE

Water Supplies of Long Island

U. S. GEOLOGICAL SURVEY
343 U.S. POST OFFICE & COURT HOUSE
POST OFFICE BOX 1350
ALBANY, NEW YORK 12201

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STATE OF NEW YORK

Department of Conservation

Water Power and Control Commission

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Engineering Report

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Water Supplies of Long Island

BY

RUSSELL SUTER

Executive Engineer

BULLETIN GW-2

LAWS 1936, CHAPTER 839

February 1, 1937

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ALBANY, N. Y., February 25, 1937

TO THE HONORABLE M. WILLIAM BRAY, *Lieutenant Governor, President of the Senate of the State of New York:*

TO THE HONORABLE OSWALD D. HECK, *Speaker of the Assembly of the State of New York:*

In compliance with the provisions of Chapter 839 of the Laws of 1936, we have caused an investigation to be made of the water supplies of Long Island.

The results of this study are set forth in the accompanying report made to this Commission by our Executive Engineer. This report is being printed and copies will soon be available.

It appears that a most serious situation exists on Long Island, gravely affecting the water supply interests of New York City and of Nassau and Suffolk counties. To remedy this situation speedy enactment of new legislation is necessary.

It is, therefore, respectfully recommended that the Legislature investigate the matter to the end that a suitable law may be formulated and enacted.

Respectfully submitted,

WATER POWER AND CONTROL COMMISSION

LITHGOW OSBORNE
Conservation Commissioner, Chairman

FREDERICK STUART GREENE
Superintendent of Public Works

JOHN J. BENNETT, JR.
Attorney General

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REPORT ON THE WATER SUPPLIES OF LONG ISLAND

Summary

Long Island ground waters are essential for the lives and activities of the people of Nassau and Suffolk counties and are a valuable, if not essential, addition to the water supply resources of the city of New York.

All of this ground water originates in rain which falls or has fallen on the island itself. The amount available cannot exceed the amount of rainfall and, as a matter of practical development, can never exceed a fraction of that rainfall.

The amount of ground water which continuously can be made available and matters relating thereto are shown in the following tabulation:

	Kings	Queens	Nassau	Suffolk	Total
Area — square miles	71	108	274	920	1,373
Average rainfall — mgd	142	216	548	1,840	2,746
Highest development — mgd	40	100	270	920	1,330
Present average pumpage — mgd	62	65	† 77	† 15	219
Safe present development — mgd	0	30	130	460	620
Additional water available — mgd	*62	*35	53	445	401

mgd signifies millions of gallons daily.
* Deficit.
† Includes some surface water.

Value of water cannot be fixed with precision, but if it is assumed for the purpose of illustration at $100 a million gallons, 1330 millions of gallons daily would represent about $50,000,000 a year. This capitalized at 4% would indicate a value for this resource of $1,250,000,000. This figure has no precise meaning, but it indicates that this is no small problem.

This property is being destroyed by unregulated exploitation. The beds under Brooklyn are nearly gone, those under Queens are going, and those under Nassau are adversely affected.

Over-pumping destroys the value of the beds by drawing sea water into them. No one knows how long it would take to freshen one of these beds when it has once been salted.

Much of the damage done can be cured and most of the expected further damage prevented by stopping pumping in the over-drawn areas until such time as they have filled up.

Before pumping can be stopped in such an area, the water now pumped must be replaced by water drawn from other sources.

Demands for water in the city of New York exceed the safe capacity of the present water works systems. Even excluding the amounts now supplied by water corporations and individuals operating wells in Kings and Queens counties, the demands on the city works are fully equal to their safe yield. This situation will grow

worse from year to year for about ten years or until Delaware aqueduct is completed as far as Rondout reservoir.

Limitation of pumping in the present depleted areas would reduce the amount of water available for the city system, deprive two large water corporations of any water supply, curtail the supply of a third corporation and stop virtually all industrial pumping in Kings and Queens, throwing, in effect, an extra burden of 100 to 150 millions of gallons daily on the city plant. This added load cannot now be carried by that plant.

New York City cannot depend on its present supplies to carry it until Delaware aqueduct is in service. Any attempt at measures designed to remedy Long Island ground water conditions would require the city to obtain additional water at once. There are no sources of supply near enough to the city to be capable of development in the time available except those on Long Island.

Recommendations:

Based on the assumption that the ground water resources of Long Island are to be saved the following is recommended:

Clothe some authority with the necessary regulative powers.

Stop or curtail pumping in depleted areas until they have been replenished.

Arrange for the supply of enough water to carry these areas during that period.

Redevelop and continue development under rigid control.

Fig. 2 — Present political subdivisions of Long Island and original subdivisions in Kings and Queens.

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REPORT ON THE WATER SUPPLIES OF LONG ISLAND

Location and Topography

Long Island lies in the Atlantic ocean off the sea coast of the States of New York and Connecticut, from which it is separated by Long Island sound and East river. The extreme westerly end forms the east shore of East river and New York bay. In shape the island has been compared to a whale heading southwesterly with its nose in New York harbor, Jamaica bay forming its mouth, and the two easterly points of the island on either side of Gardiners and Peconic bays forming the flukes. The over-all length of the main island is about 120 miles, the maximum width is about 20 miles and the land area of the main island is about 1373 square miles.

The topography of this island is reasonably uniform. The north shore is somewhat abrupt, usually formed by a bluff and, particularly in Nassau county, frequently rising to hills a few hundred feet in height. From the south shore the land rises gently to the backbone of the island, which latter structure is frequently marked by groups of hills. Along this backbone is found the maximum elevation of 420 feet in the Manetto hills. The southerly side of the island consists of plains sloping gently towards the Atlantic. The actual south shore line is ill defined, merging into salt marshes. Along all but the extreme easterly end of the southern fluke the southerly shore of the island is fringed by various beaches, sand spits and lines of dunes merging into the salt marshes on the north and with sand beaches on the Atlantic side. These sand spits average about one-quarter of a mile in width. Generally there is no break in them from Montauk Point westerly to Fire Island inlet, a distance of about 80 miles. Further west they are somewhat discontinuous and tend to overlap and are known as Oak beach, Jones beach, Short beach, Long beach, Rockaway beach and Coney island. Between the main island and the beaches lie the bays — Shinnecock, Moriches, Great South, Jamaica, etc. — which are chiefly famous for shell fish culture and recreation.

The most prominent features of the surface topography of the main island are the two glacial moraines. The older of these runs from Montauk point diagonally across the island and along the north shore of Queens. The most recent forms the north fluke and runs in a more southwesterly course, forming the main ridge in Queens and Brooklyn and continuing through Staten Island. The two cross near Lake Success.

The general type of surface topography is determined by the fact that bed rock is encountered only along East River in Queens county. Elsewhere the island is composed of sands, gravels and clays, particularly the first two. Surface streams are relatively small and unimportant. There are many ponds, most of which are of the "kettle hole" type.

Originally the greater part of the island must have been forested. Fairly heavy stands of timber existed and in part remain on the higher hills, particularly in the western part of the island. The gravel plains in the easterly end and particularly those in Suffolk county were, and much of them still are, covered with scrub pine and oak.

Glacial deposits cover all of the visible portions of the island. These were the first used as sources of ground water supply and have been the subject of many geological reports. During the last thirty years interest in water works development has passed to the lower strata, which are not glacial and not as well known.

Municipalities and Population

It naturally follows from the position of this island that it was settled early and such settlements tended to cling to the shore line. In part the building up of the central spine of the island doubtless was deterred by the difficulty of obtaining water from ordinary dug wells, as over large areas in this section the upper ground water levels are many feet below the surface. Even today the central part of the island is chiefly a wilderness. The original inhabitants of the coastal settlements largely occupied themselves with fishing, shell fish culture and off-shore whaling.

Originally this island was divided into three counties: Kings, Queens and Suffolk, reading from west to east. Suffolk county came heavily under Connecticut influences, which are still to be noted in its architecture and otherwise. Kings and Queens counties both abut on New York harbor and East river, one being south and the other north of Newtown creek. The city of Brooklyn grew up in Kings, and Long Island City in Queens. Numerous villages were established in these two counties. As time went on the city of Brooklyn spread out and eventually absorbed the whole of Kings county. When the greater city of New York was formed, all of Kings county was included in it. Only the western part of Queens was taken into the city. The eastern towns of Hempstead, North Hempstead and Oyster Bay were erected into the new county of Nassau. This history is of some importance in connection with the establishment and growth of public water supply systems which are described below.

During the last few decades the growth of population in the western counties has been most rapid. Kings is pretty much built up. Queens still contains many vacant areas, but the new subways and the World's Fair are expected to stimulate further growth.

Nassau county of late years has been tremendously developed as suburban communities. Much of the remaining area is taken up with country estates.

Suffolk has grown but has retained more of the summer resort and recreational features for which the island has long been famous. It also has its estates, many farms and large areas entirely undeveloped. The eastward march of population is shown on the accompanying diagram.

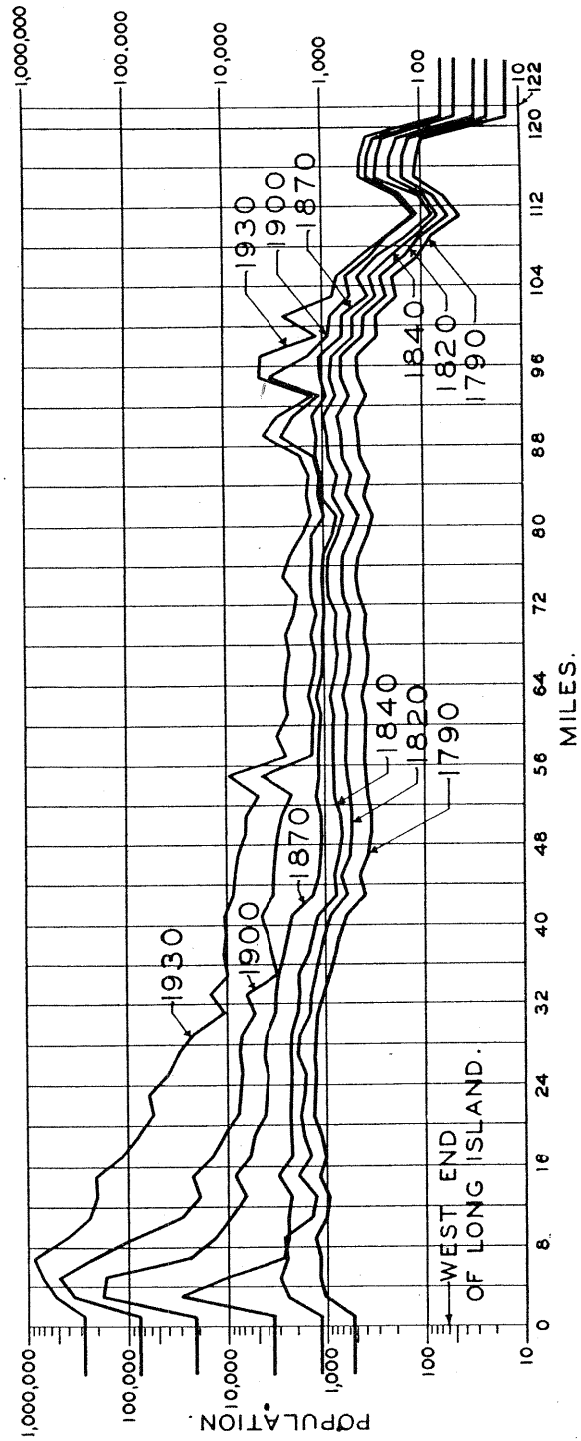


Fig. 3. Distribution of population on Long Island. Population of two mile strips projected onto axis of island. From U. S. Census Reports.

Conditions in the two easterly counties have been unfavorable to the organization of cities and villages of the ordinary type so that many centers of population which upstate would be incorporated as cities are on Long Island organized only under the town governments. Outside of New York there are but two small cities, Glen Cove (Population 18,531) and Long Beach (Population 5,817), in Nassau county. There are no cities in Suffolk county. Among the older incorporated villages are the following, the populations being as of the 1930 census:

Nassau County

Farmingdale	3,373
Freeport	15,467
Garden City	7,189
Hempstead	12,650
Lynbrook	11,993
Mineola	8,155
Rockville Centre	13,718
Sea Cliff	3,456

Suffolk County

Amityville	4,437
Babylon	4,342
Greenport	3,062
Northport	2,528
Patchogue	6,860
Sag Harbor	2,773
Southampton	3,737

There are a great number of more recent villages, most of which are very small and few of which were organized for the more general purposes for which such municipalities are adapted. Notable is the failure to incorporate such places as Huntington and Bay Shore, or even Riverhead, the county seat of Suffolk county, communities which probably would be cities if situated above the Bronx.

Upstate the desire for public utilities, including water works systems, sewerage systems and street lighting is a potent cause for the incorporation of villages. On Long Island similar results have been obtained by a great number of special improvement districts, including water districts, particularly in Nassau county. In Suffolk county by far the greater part of the public water supply systems are in private hands, chiefly New York Water Service Corporation and its associate, South Bay Consolidated Water Company.

Building of the Island

To arrive at any understanding of the underground conditions of Long Island, it is needful to inquire as to how the island was built up, that is, to go back into geologic history. To do this properly, consideration must be given to the general history of the North Atlantic seaboard, as Long Island is far from being a unique phenomenon.

All land masses elevated above sea level are subject to attack by atmospheric agencies — rain, snow, ice, frost, rivers and streams — which wear away even solid rock and carry the debris to the ocean. These processes are never ending. They have always gone on and will continue as long as rain falls. Given sufficient time any mountain range, no matter how high or how hard, will be worn down practically to sea level. Such erosion can take place only because the rocks disintegrate by the chemical action of the rain and by frost and are carried away from their original sites. The transporting agent is flowing water and the movement ends only in the ocean. On reaching salt water the debris and sediment carried by streams is dropped on the bottom. There it is sorted out, transported and leveled by ocean currents, but it remains in the general vicinity of the mouth of the transporting stream. These sediments accumulate in thickness and eventually by compression, chemical changes and sometimes by heat become consolidated once more into rocks.

Rocks above sea level are being destroyed to make new rocks under the ocean.

Geologists believe that the crust of the earth is not stable but that the relative elevations of the land surfaces and that of the ocean can and have changed and still are changing.

On all the hilly and mountainous sections of New York State and adjacent States, if the landscape is viewed from a mountain top, it will be noted that the hills, mountains and ridges tend to rise to the same general surface. This surface is not a plain, nor is it level. It slopes from the mountains towards the sea but usually passes under the unconsolidated deposits of the coastal plain before it reaches salt water. In New York State this surface passes over the tops of the Adirondacks and the Catskills. It reaches the ocean at the Connecticut shore line and passes under Long Island, which at this point represents the coastal plain and corresponds to that formation which is so marked a feature of the more southerly Atlantic seaboard States.

Geologists assume that this surface was once a nearly level plain (which they call a peneplain), about at sea level, extending some 60 miles or so further out to sea than the present shore line. The surface of this land was composed of rocks of many geologic ages from the gneisses and schists of Manhattan, Westchester and Connecticut, the older rocks of the Adirondacks, the Devonian sandstones of the Catskills, up to the lower part of the coal measures at Olean and Salamanca and younger rocks in Rockland County and elsewhere. It was worn down to sea level by the ordinary processes or erosion regardless of the age or the hardness of the rocks. This must have taken a tremendous period of time. It is dated only by the age of the sediments which have been laid

down on top of it. These latter deposits begin with what is known as the Cretaceous period of the Mesozoic era and continue, with gaps, through the Tertiary and Quaternary era to the present time; the last great changes having occurred during the Pleistocene, or Glacial period.

Geologists say that during the period of geologic history when the unconsolidated materials under Long Island were first deposited, the vegetation was not much different from that found on the world at present, but the fish were just beginning to develop bones, most of the birds had teeth, and the dominant land animals were reptiles — dinosaurs and the like.

At that time something happened to warp the cretaceous peneplain; the seaward edge was submerged and the more remote parts were raised. Immediately the elevated portions were attacked and eroded and the eroded materials were deposited on the submerged portion. This motion and general sequence of phenomena have continued with pauses and reversals until the present time and are still in progress. The result has been a vast deposit of unconsolidated materials along the Atlantic seaboard running far out to sea with a fairly gentle slope and then dropping thousands of feet into the depths. This is known as the continental shelf. Certain parts of this deposit now lie above sea level. These comprise the "tide-water" sections of the southern States, the easterly part of Maryland, Delaware, South Jersey and Long Island. It will be noted that the extent of the exposure of these deposits decreases towards the north. This is due to unequal elevation of the land. What might be a tide water section of New York, Connecticut, Rhode Island and Massachusetts is submerged under the ocean, but it actually exists. At a comparatively recent geologic date an ice cap, perhaps a mile thick, covered the North American continent from the extreme north down as far as Long Island. This ice was so heavy that it compressed and forced down the ground on which it rested. Since it melted off, the ground has been rising, this upward spring increasing rapidly towards the north. Long Island sound and the easterly extension of Long Island, Martha's Vineyard, Nantucket and George's bank are still more or less submerged. Many thousands of years hence it is probable that there will be a much greater seaward extension of New York and nearby States.

These cretaceous sediments are thicker towards the ocean, indicating that the outer edge of the cretaceous peneplain has progressively gone down during the whole period so that the rock floor, which originally was level, is now considerably curved with the convexity upwards. From this it follows that the strata first laid down might not reach as far as Long Island, and it is possible that the strata of the island itself, except possibly with extremely attenuated thickness, do not extend all the way to the edge of the shelf.

When sediment is laid down in the ocean, it tends to be sorted by waves, currents and differential sedimentation. The coarse mate-

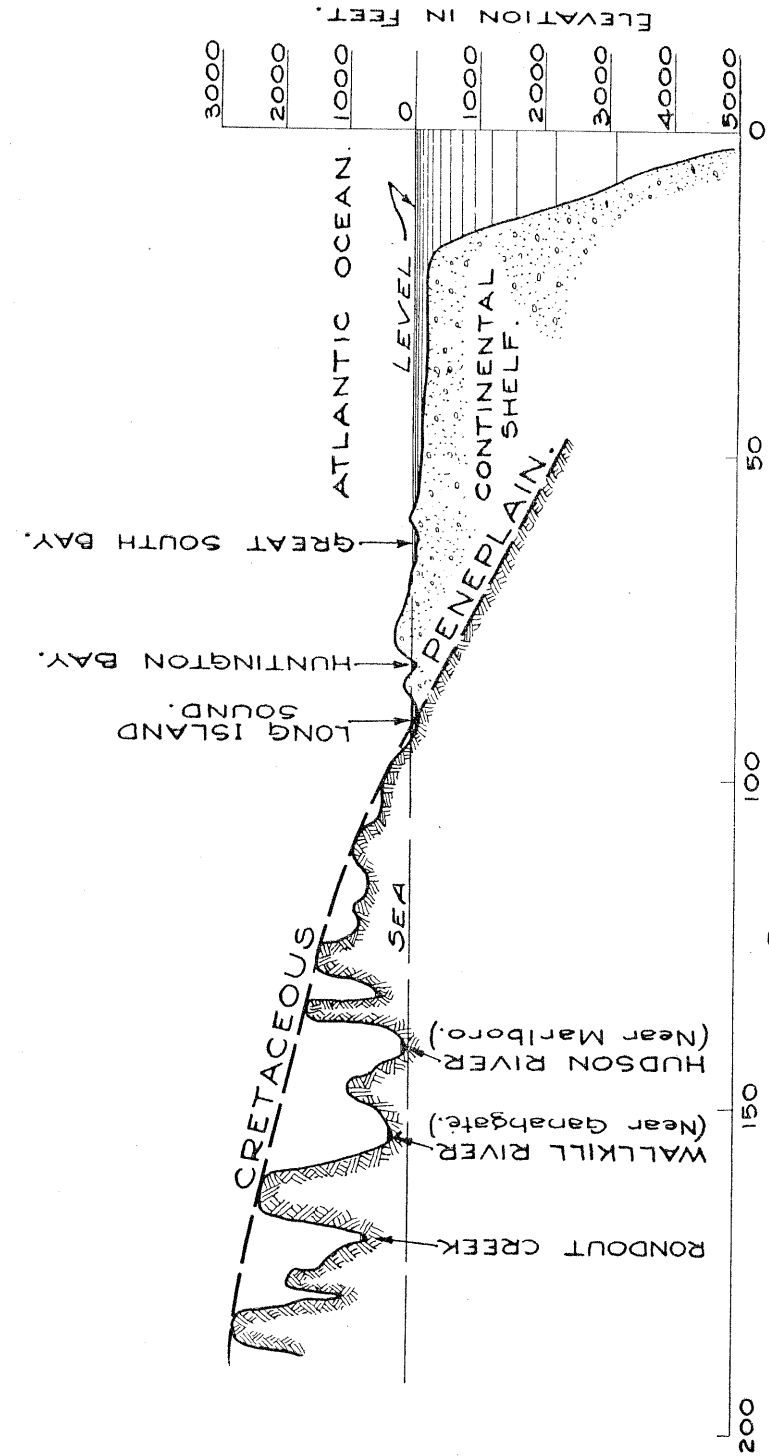


Fig. 4. Section across Atlantic coast showing Cretaceous peneplain, Continental shelf and Long Island sound.

rial is left near the coast and is there worked upon by the waves until it is reduced in size. Somewhat finer sands are washed further out to sea. Particles of extreme fineness settle but slowly and may be carried long distances from the shore. Thus the stratum laid down at any one time will probably vary from coarse pebbles on the beach to fine clay miles off shore and this stratum will be inclined rather than horizontal. With continued sinking the subsequent strata would maintain much the same sequence of materials with respect to the coast, but each grade of material in the upper stratum would be more landward than that in the stratum below it. This eventually would give a gradation from coarse to fine, proceeding upwards from the rock, but would give strata of the same degree of fineness more or less parallel to the rock surface. If a gravel bed were sought, it would be natural to look for it on the rock floor itself.

If after a period of submergence and deposition the processes were reversed and the deposited material raised above sea level, it would at once be eroded and cut by stream valleys. On again being submerged there would be fresh deposits on the eroded surface and the fineness of such new deposits would decrease upwards as before. Of necessity the water-bearing beds are of coarser texture, so under Long Island such beds would be expected on the rock and on subsequently eroded surfaces, usually clay. Such conditions are found. It will be noted that a gravel stratum tends to be held

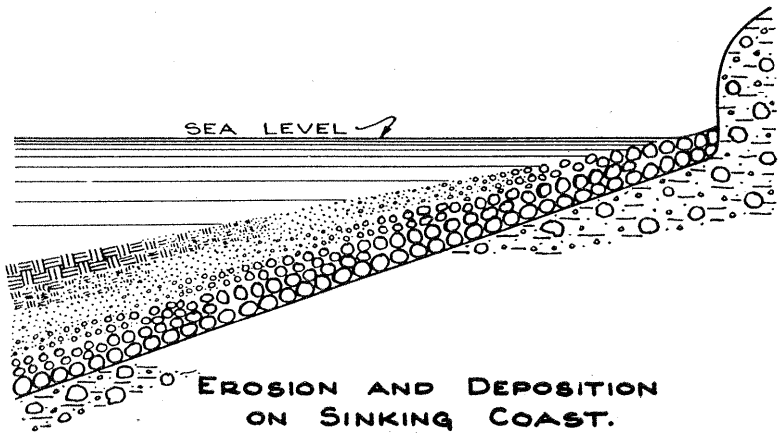


Fig. 5. Gradation of size of beach deposits when coast is sinking.

between clay beds and also tends to become finer and eventually to run into clay at the seaward end. Actually Long Island is the shoreward margin of a vast deposit of unconsolidated material resting on a rock floor, the ancient peneplain. The surface of the rock is fairly regular, slightly concave in a horizontal plane, ap-

pearing above the ocean along the Connecticut shore and close to East river in western Queens county and sloping in a generally southeasterly direction about 64 feet to the mile.

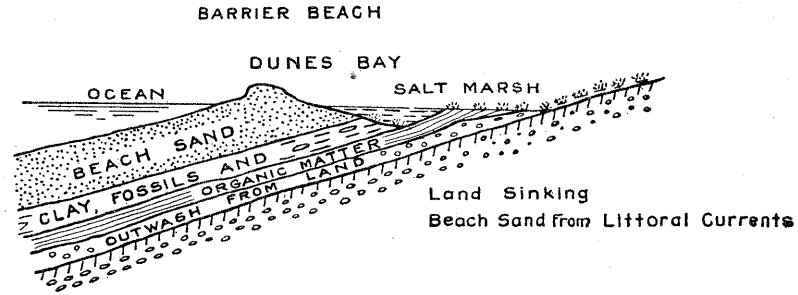


Fig. 6. Stratification resulting from a bay behind a barrier beach on a sinking coast line.

Over this rock floor have been deposited many layers of sands, gravels and clays. Each layer tends to be thicker towards the ocean, coarse at the bottom, finer at the top. There are evidences of intermediate elevation and erosion. Some formations found in New Jersey do not occur in Long Island and vice versa. Probably these beds once lapped over into Connecticut and have been eroded to form Long Island sound. None now pass the Sound.

Long Island sound is not an isolated phenomenon. It happens to be submerged because this part of the coast has not yet fully recovered from the depression of the ice age, but it is the easterly extension of the trough which is occupied by Delaware river from Trenton to Wilmington, by the upper end of Chesapeake bay, by the Potomac for a considerable distance below Washington and presumably extends further south. It follows the line of junction between the coastal plain and the Cretaceous peneplain and nearly coincides with the "Fall Line" of the southern seaboard States.

Finally an ice cap formed on the northerly portion of the continent and extended by outgrowth and actual motion down to and perhaps over Long Island. It is supposed that this ice may have been a mile in thickness and that it moved towards the ocean. This doubtless had its effect in deepening the sound and in steepening the northern shore of the island, carved out the bays to some extent, deposited the moraines where the edge of the ice stood and melted, formed the outwash gravel and sand plains and the "kettle holes" and generally covered the old surface, profoundly modifying the pre-existent topography. Elsewhere in Europe and this country the glaciers advanced and retreated several times. Geologic opinion differs as to the multiplicity of ice activities on Long Island, but it is agreed that there were at least moderate advances and retreats of the ice. There is no certainty that these conditions will not recur. Interglacial epochs undoubtedly occurred in

Europe and it may be that we are living in one today. It seems probable that Long Island was considerably elevated above the ocean before the ice came down, perhaps sufficiently so that the whole continental shelf was bare. At least the gorge of the Hudson can be traced right across the shelf. At the close of the period it seems to have been below sea level and to have been rising since that time.

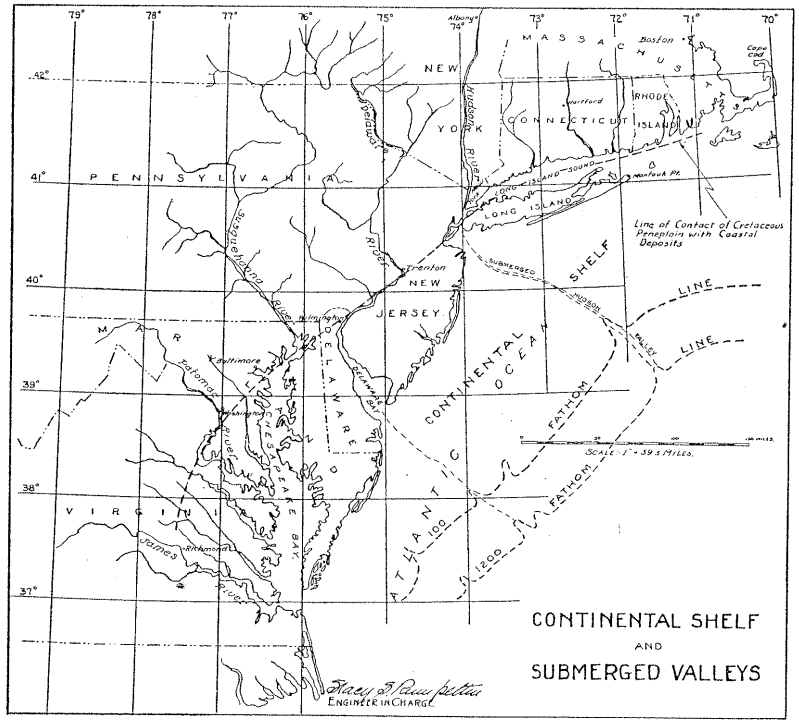


Fig. 7. Atlantic coast from Massachusetts to Virginia showing contact of Cretaceous peneplain with coastal deposits, continental shelf, change in direction of rivers and submerged valleys.

There are three classes of deposition resulting from the advance and retreat of the ice cap. As the ice approached, the greater stream flow resulting from the summer melting of the ice along the front eroded larger valleys and also deposited great quantities of stream and river gravels. Under the ice there was a deposit of material principally to be distinguished by the fact that it was not sorted by the water and, therefore, is a mixture of all grades of fineness. Further north this takes the form of hardpan or till, but on Long Island it does not appear generally to have been consolidated to that extent. At the extreme limit of the ice cap or

wherever it stood for considerable periods of time, deposits of unsorted and unstratified material of all shapes and degrees of fineness and frequently of great volume were left. These are the moraines. In front of the final advance of the ice and following

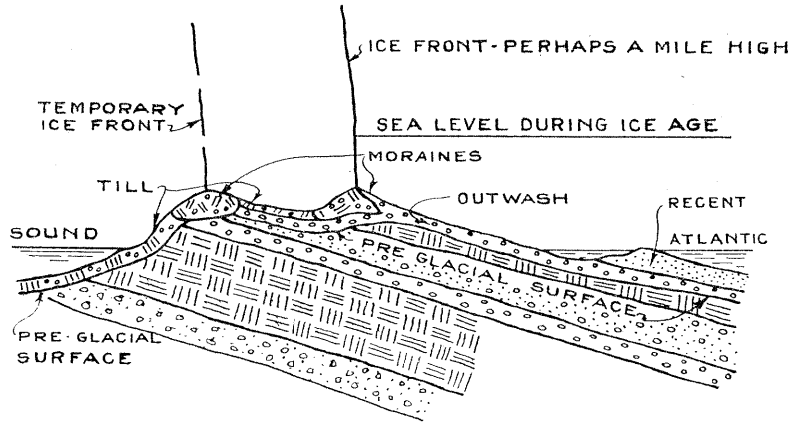


Fig. 8. Section of Long Island and Wisconsin ice cap.

up on its retreat are further outwash gravel and sand plains. These are the most conspicuous features of the southerly side of Long Island.

The present stream valleys, the barrier beaches and salt marshes have been formed since the retreat of the ice.

Origin of Long Island Ground Water

A much idealized section through the island is shown. It will be noted that none of the unconsolidated strata cross the Sound and that practically all of the deeper water-bearing beds are below sea level. In spite of this, these beds carry fresh water and in most wells sunk to them the fresh water rises to a point higher than sea level, sometimes higher than the ground surface. One of the most vital problems in this study is the determination of the origin of this water.

All fresh water in, on or under the earth originally came from rain or snow. This can confidently be stated as a universal truth. Therefore, the Long Island ground water came from rain, but it is important to determine where that rain fell. Here we pass into the realm of speculation, not necessarily because the facts cannot be established or interpreted, but because the present knowledge of underground conditions on Long Island is lamentably scanty. Rainfall on the island averages about 42 inches a year but varies somewhat from place to place as shown on the accompanying map. It also varies from year to year as shown on the diagram.

Rain which falls on the earth may be evaporated, either directly or through the medium of growing plants; it may run over the surface of the ground into streams or sink into the ground and emerge elsewhere as springs and so enter the streams; or it may sink into the earth and flow away through it to the ocean. Various special names have been given to these several parts of the precipitation, but the most descriptive of these terms are respectively: fly-off, run-off and sneak-off. Of these the last is unusually large

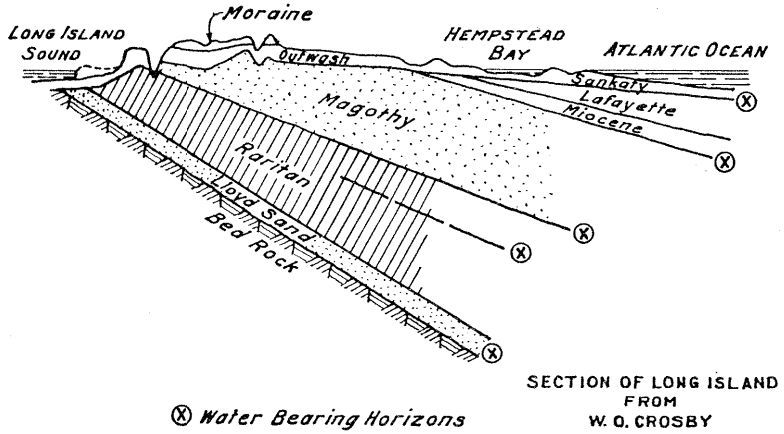


Fig. 9. Section of Long Island showing geology. From Prof. W. O. Crosby.

on Long Island, estimated at over half of the total precipitation, whereas in most places it is almost negligible. This is due to the absence of steep slopes and the loose and porous nature of the surface material over the greater part of the island. This material allows the rain to sink immediately into the ground. In other words, the top of the island, at least, has the nature of an enormous sponge. This fact may and does account for the water in the upper strata, but it does not show how the water gets into the lower strata. The fact that it occurs in the lower strata is the more remarkable because these water-bearing beds usually are separated by impervious beds of clay which may be many feet in thickness. It is an important question and one about which as yet little is known, except that the water gets to them and in sufficient volume and under sufficient head to keep the salt water out.

There are several theories which are illustrated by the accompanying diagrams. Clay is only relatively impervious; water flows through it, but only slowly. It may be that these lower beds have been filled with water percolating through the clay during past ages, are now full of water and this water can be pumped out, but that the amount of such water is strictly limited, is replaced but slowly and if heavy pumping is long continued, the fresh water

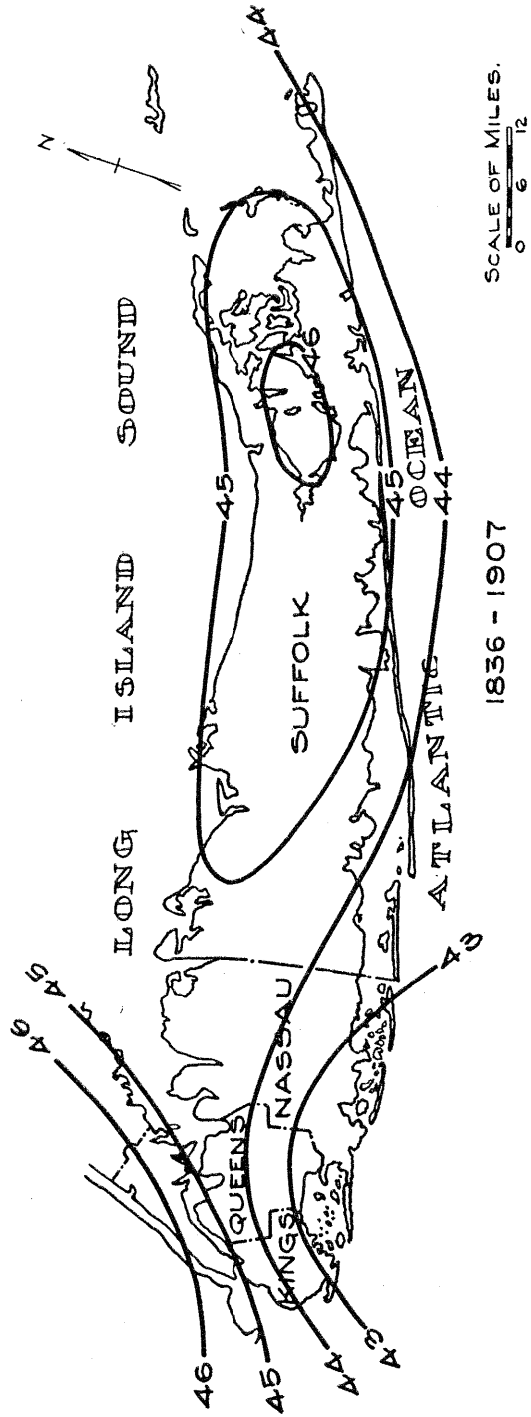


Fig. 10. Lines of average equal annual rainfall on Long Island for period 1836 to 1907.

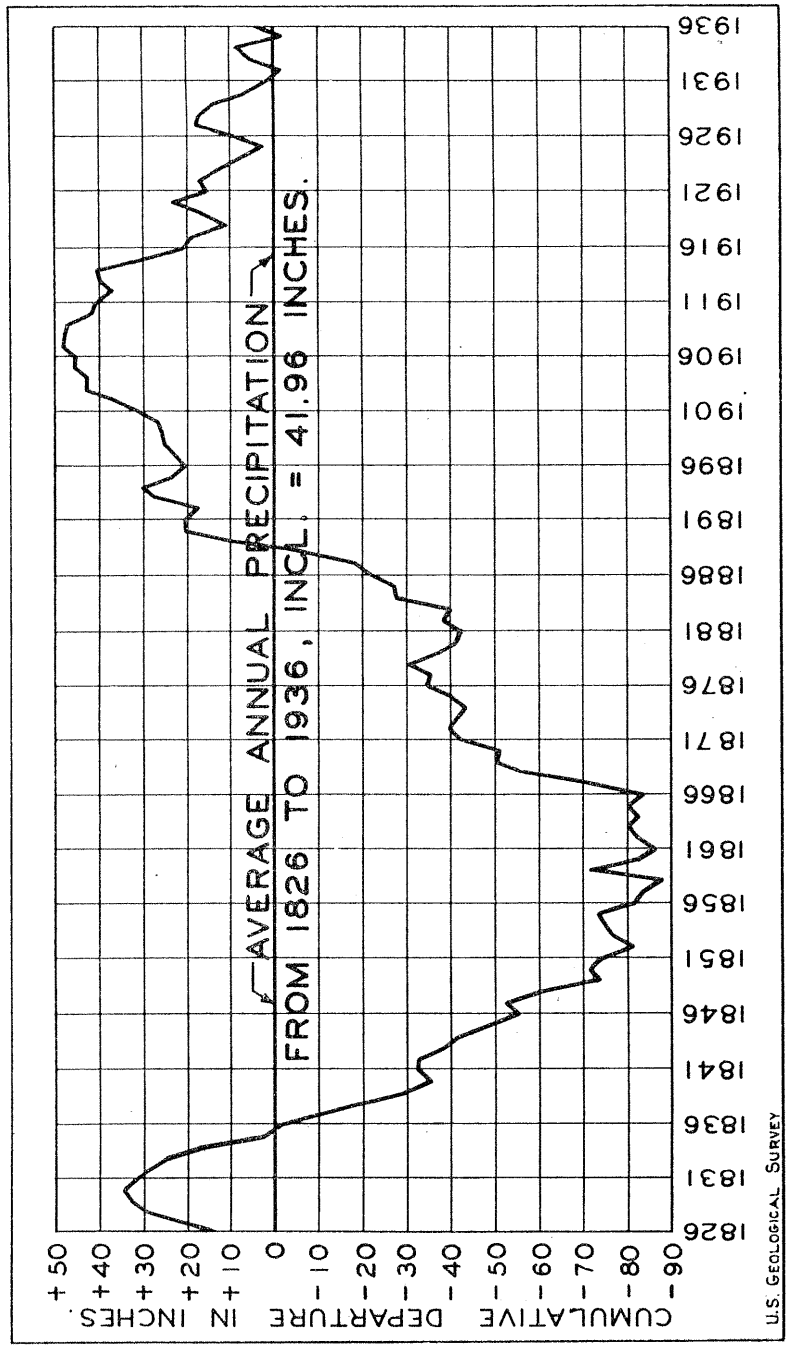


Fig. 11. Cumulative rainfall curve for Long Island for period 1826 to 1936.

will be exhausted and replaced by salt water. Another theory is that the clay beds generally are not continuous but form lenses of limited area in the sands and gravels so that the ground water

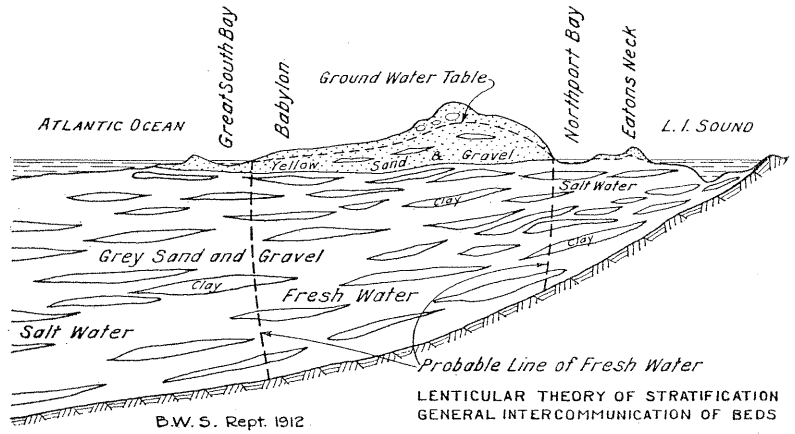


Fig. 12. Ideal section of Long Island showing theory as to lenticular form of clay deposits.

flows around them and all the water-bearing beds of the island are interconnected. As it is reasonably certain that in places the hydraulic gradient of the ground water in the lower beds differs from that in the upper beds, this last cannot universally be true. It is possible that the clay beds originally were continuous over wide areas but that subsequent erosion has cut river valleys through them which later became filled with porous materials through which water can circulate from bed to bed.

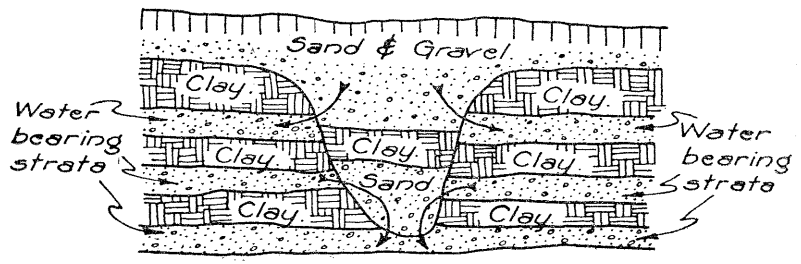


Fig. 13. Possible interconnection of water-bearing beds through filling of a buried pre-glacial valley.

Probably these theories are all more or less true. The facts must be discovered and can be worked out by intensive study of well locations and water levels in wells sunk to the different strata. This work is in the hands of the United States Geological Survey,

which has been working on the problem for several years, but so far has not reported its findings.

There is a theory prevalent on the Island and held tenaciously by many that these ground water beds are fed by rain falling on Connecticut. Under the right combination of circumstances such condition might occur, but in this case no suitable gathering ground can be found in Connecticut, no strata that could carry the water under the Sound can be discovered and the shape of the ground water surface entirely negatives any such view.

Generally over Connecticut the unconsolidated material resting on the rock is thin and the rock itself is hard and impervious, except perhaps in the Connecticut valley. None of the unconsolidated beds of the Island cross the Sound. For Connecticut ground water to reach the Island, it would have to pass through the schists and gneisses of the underlying rock floor. Even a casual examination of these rocks should convince any one that passage of large volumes of water through them is well-nigh impossible. If, as seems to be the theory of the supporters of the Connecticut origin of the water, there were a water-bearing stratum running from Connecticut under the Island and out to sea, it would be necessary to drill into this stratum to obtain water. The depths of such wells would vary over the Island as do the wells sunk to the Lloyd's gravels, the formation which rests on the rock floor. The level to which water would rise in such wells would be an inclined plane sloping southeasterly from the catchment area. No such strata have been found and practically no Long Island wells, except in Long Island City, have been drilled in the underlying

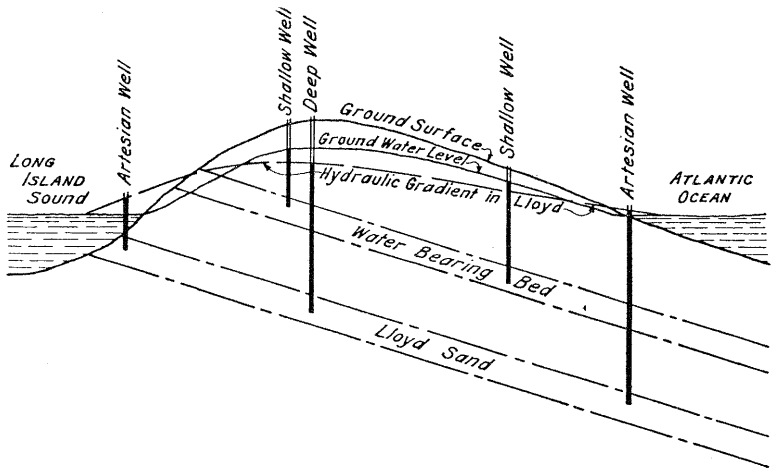


Fig. 14. Section showing difference between upper ground water surface and piezometric water surface in Lloyd gravel.

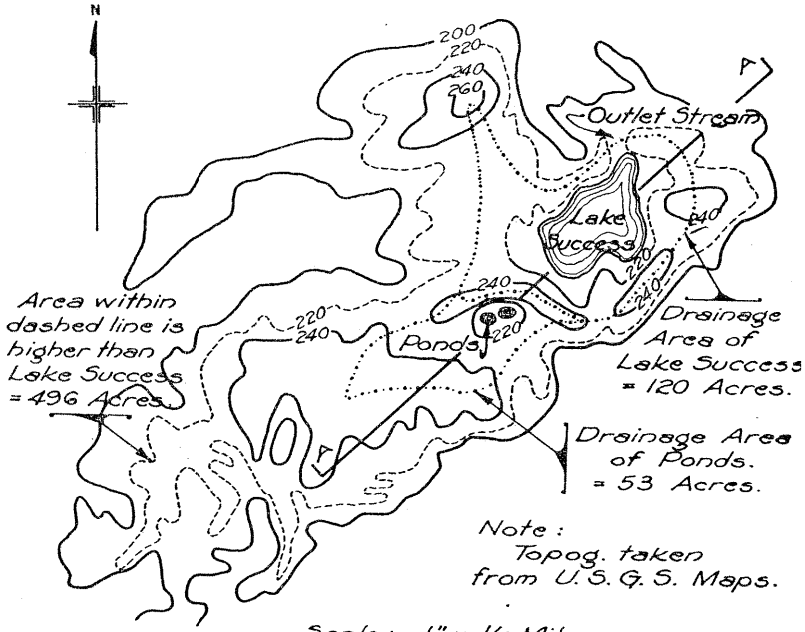
rock. The many known water-bearing beds do not run under the Sound to Connecticut. In all known beds the shape of the water table conforms more or less to that of the island. That is, it is higher under the backbone of the island than at the shores. This means that all beds so far developed must be fed by rain actually falling on the Island itself. There is no evidence of any other origin for this water and the rainfall on the Island is ample to supply all water known to be available. The actual failure of the water-bearing beds under Brooklyn supports this theory of local origin as it proves the total amount of water available to be strictly limited.

One case frequently cited in support of this theory is Lake Success, which is said to have no tributary watershed but to have a continuous outflow. The United States Geological Survey long ago reported that this lake is formed in a "kettle hole." As the glacier melted, a berg or block of ice was stranded at this point, where the bottom happened to be hardpan. Perhaps it forced its way down into the underlying material, thus forming an impervious basin. Gravel and sand were deposited about this ice mass by the turbulent streams or currents flowing from the melting glacier, perhaps burying the berg. Eventually the ice melted and left a depression in the gravel deposit. As this gravel rests on a more or less horizontal bed of hardpan, this depression later became a pond. It is fed through the gravel by a small but adequate watershed consisting of a mass of porous material surrounding the pond and resting on the impervious bed. It is so porous that the percentage of rain caught and delivered underground to the pond must be relatively high. To come from Connecticut it would be necessary for the water to rise vertically through the soil into the bottom of the pond. Not only is the bottom of hardpan, which would not lend itself to such method of refill, but the gravel deposit under this till bed is dry.

It must be assumed that the natural water supply resources of the Island cannot exceed the total rainfall on the Island and in fact are nearly limited to that fraction of rainfall which gets into the ground and is not evaporated by plants—in other words, the "sneak-off". Ultimately the problem resolves itself into one of increasing the "sneak-off" and devising means of capturing the greatest possible amount of it.

Man cannot control the rainfall, it is part of the weather. Evaporation or "fly-off" is most active from open bodies of water and from and through vegetation. A summer shower falling on a forest hardly reaches the ground and is all evaporated. The "fly-off" from a forest during the growing season is greater than the evaporation from a free water surface. That from a growing hay field is yet greater. In other words, the more open water, the more trees, grass and crops, the less the "sneak-off".

Anything which renders the surface of the ground impervious reduces the inflow and increases the "run-off". Paved streets,



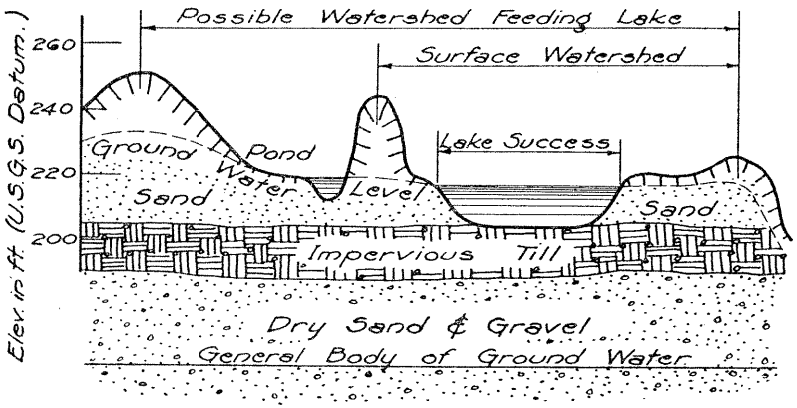


Fig. 15. Lake Success—showing underlying formations and disconnection with general body of the ground water.

Area No.	Percent of Perviousness
1	75
2	85
3	63
4	39
5	49
6	100
7	100
8	63
9	75
10	26
11	100
12	75
13	39
14	26
15	63
16	49
17	75
18	85
19	92
20	75
21	92
Total	80.6

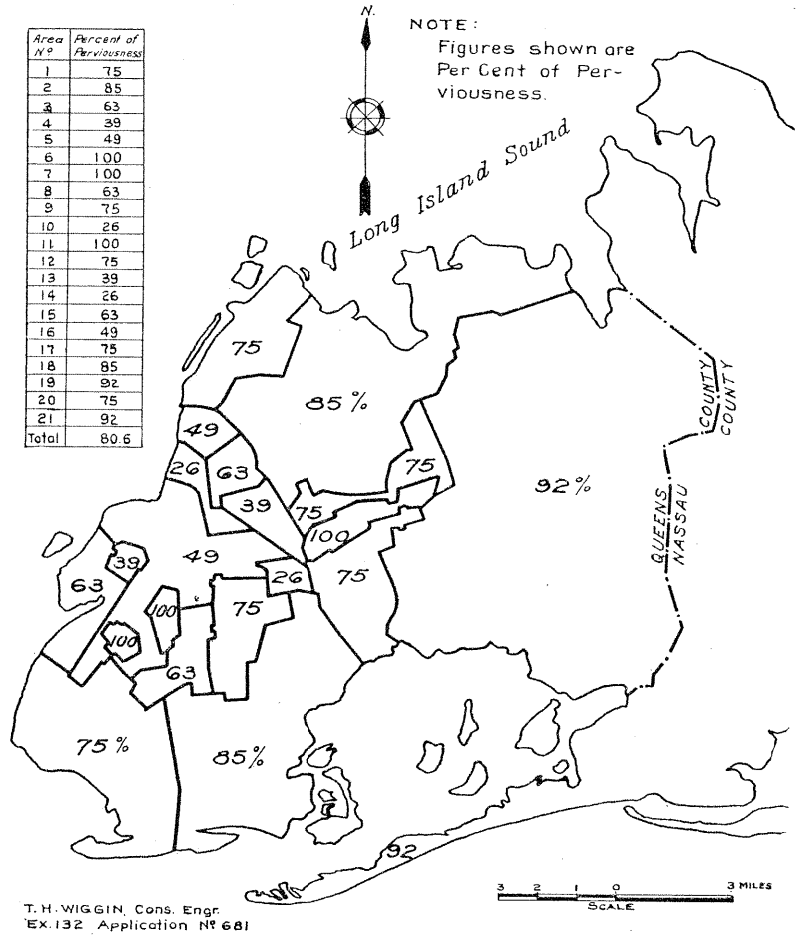


Fig. 16. Surface porosity in Kings and Queens counties.

Area No.	Location	Percent of Perviousness
1	Bay Ridge and Bensonhurst	75
2	Canarsie and Sheepshead Bay	85
3	Red Hook District	63
4	Red Hook District	39
5	Wallabout and So. Brooklyn	49
6	South Brooklyn District	100
7	Flatbush and So. Brooklyn	100
8	Flatbush District	63
9	E. Flatbush District	75
10	E. New York District	26
11	Cypress Hills District	100
12	Glendale District	75
13	Bushwick District	39
14	Williamsburg District	26
15	Williamsburg District	63
16	Greenpoint District	49
17	Long Island City	75
18	Corona—Flushing	85
19	Queens—Jamaica	92
20	E. New York District	75
21	Rockaway	92
	Total	**80.6**

roofs and similar structures concentrate the rainfall in certain spots and so make it easier to flow over the land than into the ground. If this concentrated rainfall is taken into a sewer or drain and carried away into the ocean, the amount so discharged is irrevocably lost to the ground water. Deep sewers, subways and the like drain the upper layers and usually discharge outboard of the Island. These effects have greatly reduced the inflow to and possible yield of the ground water beds of Kings county and the effect is moving eastward. Much of this cannot be avoided, but it must clearly be borne in mind that every drop of water pumped from a well into a sewer, every drop of rain discharged to a sewered catch basin and every drop of water drained from the ground is, except in the few cases where sewers discharge back into the ground, forever lost to the ground water.

Amount of Water Available

Rainfall on Long Island varies considerably in amount from year to year. It averages about 42 inches. This amount of rain water is the equivalent of two million gallons on a square mile in a day. If there were no evaporation and sufficient storage that would be the safe yield of any square mile. As there are 1373 square miles of surface on the main island, the maximum safe yield must be less than 2746 millions of gallons daily.

It has been estimated that in favored locations about 1.25 millions of gallons of water per square mile can be obtained daily. In this report it has been assumed that the maximum attainable is one million gallons daily from each square mile of island surface. There is no hope of actually reaching that figure.

This gross expectation of yield must be reduced by the amount of rainfall that is drained away to salt water, or as it has at times been expressed, by the permeability of the surface. Brooklyn is highly impermeable, but Suffolk county remains nearly in its natural condition.

Topography affects yield. Thus salt marshes and outlying islands, points and "necks" are unfavorable, but nearly level sand plains extending well inland are favorable to development. Even so, by suitable methods, intercepting surface flow and the right sort of wells, these unfavorable areas could be made valuable.

My estimates are:

	Kings	Queens	Nassau	Suffolk	Total
Area — square miles	71	108	274	920	1,373
Average rainfall — mgd	142	216	548	1,840	2,746
Maximum natural yield — mgd	89	135	342	1,150	1,716
Minimum natural yield — mgd	71	108	274	920	1,373
Yield reduced by sewers, etc.— mgd	40	100	270	920	1,330
Safe present development — mgd	0	30	130	460	620

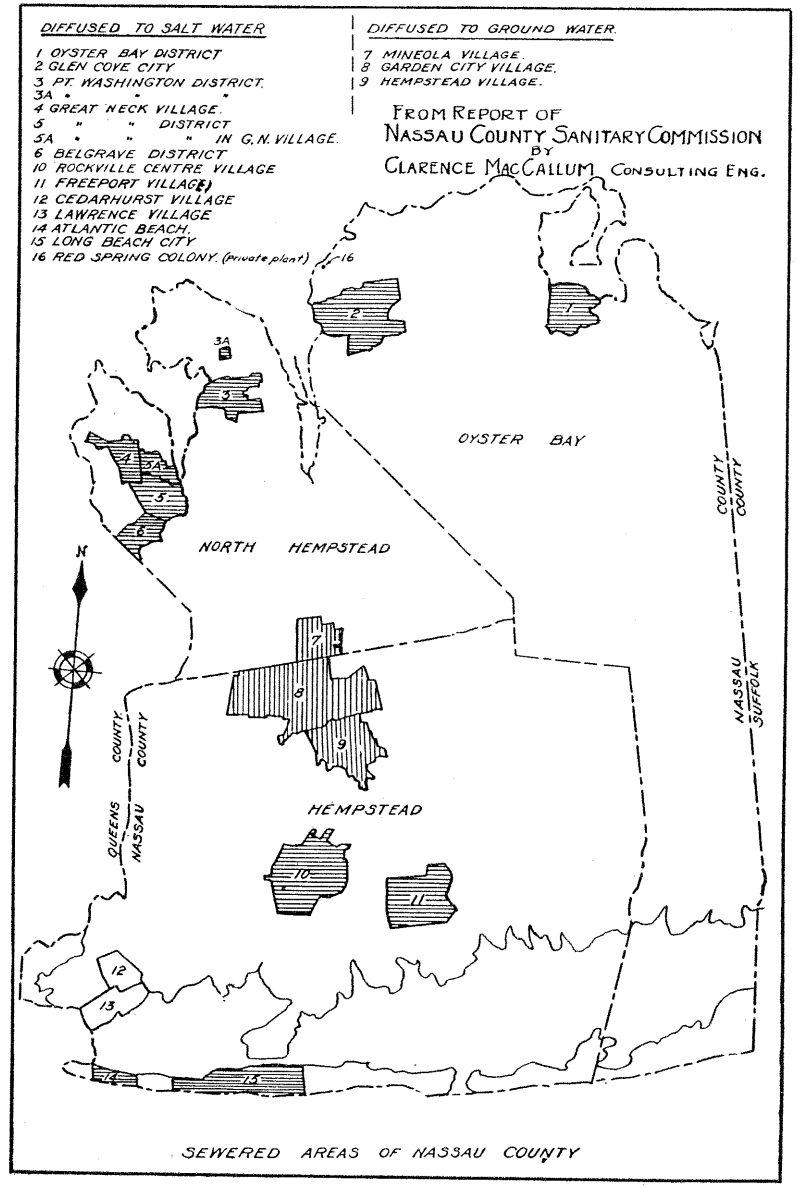


Fig. 17. Sewered areas in Nassau County.

The second line from the bottom represents my estimate of the ultimate amounts of water that could be obtained. To obtain these amounts presupposes that the island was first restored to normal ground water conditions, that all wells were part of an island-wide system, that there existed precise knowledge of underground conditions and that there had been great advances in the art of developing ground water. Such results cannot be achieved today. Perhaps they are impossible.

The last line shows more nearly what could be aimed at today. In theory the Kings and Queens rates could be increased after the Brooklyn depression is removed, but by that time more sewers would be reducing the replenishment of the ground waters in those counties.

Even with the best of development it is probable that some of the water would have an unduly high chlorine content and probably could not be used for drinking purposes. Such water would have value for condensing and cooling and in certain industrial processes.

All this presupposes the use of underground storage; that is, the ground water levels would fluctuate considerably from month to month and from year to year.

Lack of elevated storage requires that for a given average draft pumps and wells of rated capacities frequently of three or four times that draft are required. Conversely the average draft cannot be determined by consideration of the installed capacity alone, as it depends on the seasonal variations in use of water.

Thus a new highly seasonal demand, such as air-conditioning or irrigation, by increasing the peak load would diminish the average capacity of an established plant, but a new heavy off-peak load could be carried by the installed capacity with a resultant increase in the average.

Regulation must be based both on peak and annual draft. This requires the installation and frequent reading of meters and greatly complicates and increases the cost of supervision and control.

Highest development would be possible only with one unified system for the whole island. A number of large systems—say three to six—under close regulation could approximate to high efficiency. Under piecemeal and individual development, sufficiently close control to give such a total yield would be impossible.

Growth of Public Water Supply Systems

Early development of the water supply resources of Long Island was started by the city of Brooklyn. At the time the greater city of New York was formed Brooklyn had been enlarged to cover the whole of Kings county and was pumping water from numerous stations along the south shore of the Island extending from near Ridgewood reservoir in Kings, through Queens and nearly across Nassau county. Not until Catskill water was delivered into Brooklyn in 1917 was any water of other than Long Island origin available for that city. It has been said that need for a more liberal supply of water had its weight in deciding the people of Brooklyn to become part of the greater city.

Consolidation came about in 1898. At that time New York was starting to seek other sources of water supply. As always, it had started late and it did not begin work until after 1905. In the interval Brooklyn could not wait and developed additional Nassau county sources (Water Supply Application No. 50; approved May 15, 1909), of which the 72-inch steel pipe line along Sunrise Highway and Hook Creek pumping station are the most notable units.

Originally Brooklyn was supplied with surface water. On the small streams flowing to the sea and bays along the south shore, reservoirs were constructed, pumping stations installed and an aqueduct built running to Ridgewood pumping station and reservoir. These reservoirs still exist but in large measure have been turned over to park authorities. Sunrise Highway has been constructed over the aqueducts but does not interfere with them.

At a later date shallow wells were sunk near these reservoirs and water pumped from them into the aqueduct. In general these wells were put down in groups of considerable numbers, all served by a common suction pipe. In some cases artesian flow was available to deliver water directly into the aqueduct. In that case the water had to be pumped at intervals along the aqueduct. As time went on wells were sunk to greater depths but deep well pumps have not been used. The sum of the maximum average rates of pumping from these sources is about 160 million gallons daily, but that amount of water could not now be obtained. Wells and ponds have been abandoned, wells need reconstruction and in many cases the water-bearing beds have become salted so that certain stations are no longer of value.

That part of Brooklyn known as Flatbush (the former town of that name) has always been supplied by private effort and by wells sunk in the area. The Flatbush plant of New York Water Service Corporation now has some 140 wells from 85 to 500 feet in depth, the latter ones of the deep well turbine type, and it distributes some 25 millions of gallons daily to about 200,000 people.

What is now the borough of Queens, Long Island City, the villages of Flushing, Whitestone, College Point and Jamaica, the Rockaways and the northeasterly section of the county were equipped with public water supply systems. At the time of consolidation some of these systems were publicly owned. The large ones, Jamaica Water Supply Company, Citizens' Water Supply Company of Newtown, Queens County Water Company (now Long Island Water Company) and the plant in Woodhaven, now owned by New York Water Service Corporation, were in private hands. Those parts of the plants of Long Island Water Company and of the Citizens' Water Supply Company of Newtown, which were within the city limits, were later taken over by the city.

Except for Catskill water, Queens county is supplied entirely from wells, of which there are now in use and pumping for public purposes 620 wells supplying 45 millions of gallons daily. The draft at one time or another has been as high as 62 millions of gallons daily.

Except for the Brooklyn development, Nassau county hardly started to put in water supply systems prior to the beginning of the century and real activity started along about 1910. A large area along the south shore, Great Neck, Glen Cove and Sea Cliff are still supplied by private effort, chiefly by the plants of New York Water Service Corporation and the Long Island Water Company. Most public development has been by water districts. Most of the water comes from deep wells of the gravel strainer type pumped by electrically operated deep well turbine pumps. Virtually the whole population of the county, 352,000, is supplied and pumping runs about 32 millions of gallons daily for use in the county and about 24 millions of gallons daily for use in New York City.

In Suffolk county development began fairly early and has continued steadily. Most of the plants are privately owned and in fact most of them are owned by the affiliated companies, New York Water Service Corporation and South Bay Consolidated Water Company. The population is about 180,000 and a high percentage of it is supplied with water. The pumpage for public and institutional water supply purposes is estimated at about 15 millions of gallons daily.

Private and Industrial Pumping

In these counties there is a multitude of private wells, mostly driven and of the individual household type. These are of small diameter and small capacity, but the aggregate pumpage must run into a fairly high figure. However, most of this individual household pumpage does not affect the ground water, as the water used goes back into the ground.

In addition there are many fire wells. This is an unusual method of providing water for fire fighting. Four-inch and six-inch wells are put down along the streets and so arranged that fire pumpers can hook on to them and pump water directly from the ground on to the fire. Of course, the actual total draft from them, even in the aggregate, is small and most of it returns to the ground.

Added to all these is the industrial pumpage about which little has been known prior to 1933. Up to that time it was thought to be of small amount. It was then found to be about 40 millions of gallons daily in Kings alone (with a maximum of nearly 60 millions in 1928) and perhaps 20 millions of gallons daily in Queens and to be a most important factor in the use and depletion of the ground water resources of the Island.

All these rates of pumpage and the past history thereof are shown in the accompanying Fig. 21. The amounts of pumping

for public water supply systems were obtained from figures compiled by the United States Geological Survey. Industrial pumping figures were collected by Mr. Angus D. Henderson. These figures do not take into account pumpage from wells used solely for air-conditioning and condensing where such water is all diffused back into the ground. In those cases the pumpage does not materially affect the ground water. The amount so pumped is perhaps six billions of gallons in a year, averaging about 16.5 millions of gallons daily, but is seasonal and the peak load may amount to as much as 84 millions of gallons a day. As above stated, it has been found possible to diffuse this water back into the ground, so that the net effect on the ground water levels is practically nil.

For many years pumping from wells was general only when the surface of the ground water was within suction limit (about 20 feet) of the surface of the ground. Some pumps were placed in pits in order that lower levels could be reached and there were some deep well plunger pumps and air lifts in use. The development of the deep well turbine pump changed all this and made it possible to follow the water surface down to considerable depths and to increase the drawdown in existing wells, thus increasing their capacities. This invention, together with the development of the large diameter, gravel walled, large capacity well has made possible the serious condition of ground water depletion which now exists in Brooklyn. This new type of well, typified by those put down by the Layne Company, although not exclusive with them, came in at the same time as the deep well turbine pump and is now the favored type on Long Island.

All this came to a head just after the World War and resulted in a large increase in industrial pumping. Wells once down in the cellar or yard of an industrial plant are not conspicuous objects and the multitude of large diameter and capacity wells put in in the last two decades failed to be noticed, nor were the profound changes produced by them really known until about 1933.

The Problem of Well Location

As above stated, the first developments drawing large quantities of well water from the Long Island formations were made by the city of Brooklyn and its successor, the city of New York. These wells were located near the ponds, pumping stations and aqueducts which had been built some years previously. These locations were obvious and, as the aqueducts were built and the city in many cases owned the land, they were cheap. Actually the wells tended to dry up the ponds or reservoirs so that the increase in the available yield was not as great as might have been expected.

A theory has been advanced by many that the proper way to develop the underground resources of the Island to their maximum capacities is to place the wells close to salt water and in effect to intercept the fresh water that is flowing from the Island towards the sea.

This theory has much plausibility and with modifications is basically correct. There is, however, always a chance that it was formulated partly on existing practice and partly on analogy with surface water conditions. In any event it is proper to re-examine this theory to determine whether it is actually the most effective way of developing the Island sources.

It is well known that if a well is sunk into a water-bearing stratum the water will rise in it to a height which is the level of the ground water table in the upper beds or the analogous piezometric surface in the lower beds in which the water is confined by overlying impervious strata.

If a pump is put in the well and operated, the water level in the well must be drawn down by the amount of head necessary to force the amount of water pumped through the surrounding ground and the well screen. In uniform strata the profile of the water table under such circumstances would be as indicated in the accompanying figure, that is, it would resemble the bell of a trumpet with the small end down and coinciding with the barrel of the well. With confined strata a similar effect would be produced in the piezometric surface. This surface is theoretical and can be demonstrated only by sinking a number of wells to the stratum in question and determining the water level in them, but it acts exactly like the free ground water surface and there is no need to differentiate between them at this moment.

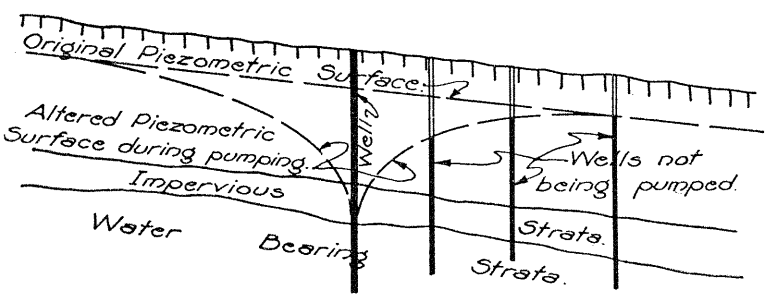
Salt water is heavier than fresh water, the relation being as 1.025 to 1, or a column of salt water 100 feet high will balance a column of fresh water 102.5 feet high.

If the well is located close to salt water and heavily pumped, the ground water table between the well and ocean may be so lowered as to cause salt water to run into the well, even though the intervening ground surface may be above sea level. In practice this fact has too frequently been overlooked with unhappy results. This makes it clear that heavily pumped wells should not be too close to salt water nor should they be too low in elevation if salting of the strata is not to result.

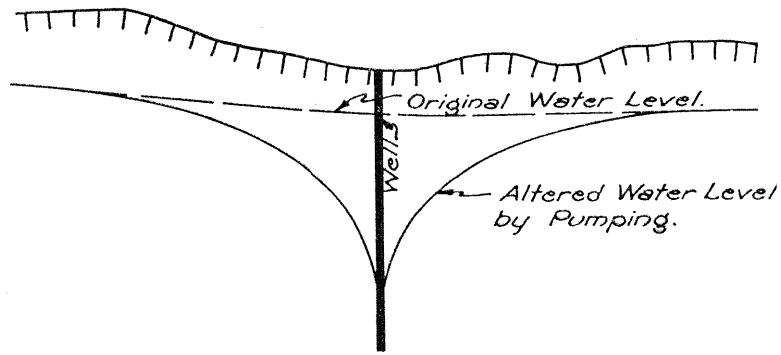
If Long Island were composed entirely of a uniform mixture of sand and gravel, the water table and line of junction between fresh and salt water would be as shown in the cut and pumping from wells would cause the intrusion of salt water in parts of the beds as indicated.

Study of this section suggests that if it were desired to pump the maximum amount of water possible from such an Island without salting the beds actually tapped, but with as full development of the underground storage as could be obtained, the wells should be located inland. This would be an expensive type of development, requiring deep wells and high pumping lifts, but the cost might be justified if the need for water was sufficiently great.

Long Island is not a mass of uniform material, it is stratified and the different water-bearing beds are separated by heavy beds



TYPICAL CONE OF INFLUENCE OF A DEEP WELL.



TYPICAL CONE OF INFLUENCE PRODUCED BY PUMPING A WELL.

Fig. 18. Cones of influence of wells sunk in different strata.

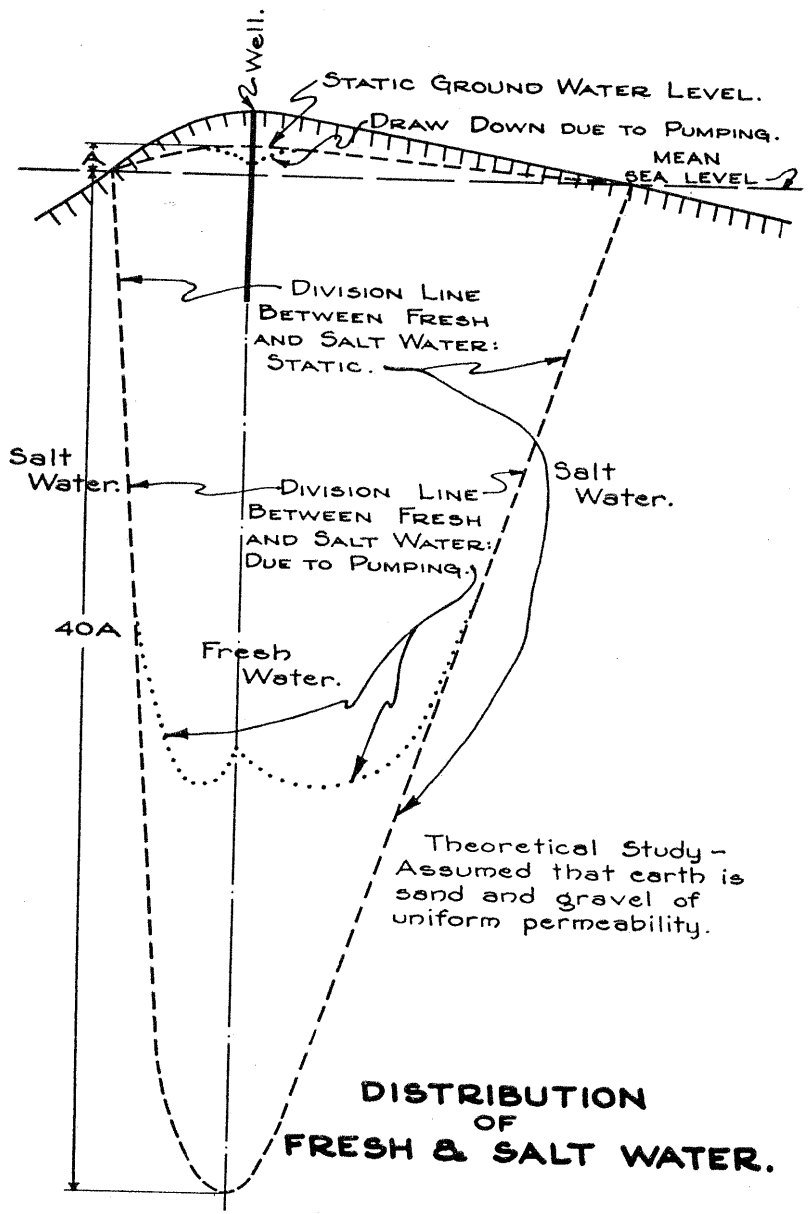

Well.
Static Ground Water Level.
Draw Down due to Pumping.
Mean Sea Level
Division Line Between Fresh and Salt Water: Static.
Salt Water.
Division Line Between Fresh and Salt Water: Due to Pumping.
Salt Water.
40A
Fresh Water.
Theoretical Study - Assumed that earth is sand and gravel of uniform permeability.
DISTRIBUTION OF FRESH & SALT WATER.

Fig. 19. Section of ideal island showing distribution of fresh and salt water in the absence of impervious strata.

of impervious clay, many of which are continuous over wide areas. This condition makes possible the pumping of fresh water from the Lloyd formation on Long Beach and from higher levels on Fire Island beach, although in both cases the land surface in which the wells are sunk is surrounded by and the wells themselves are close to salt water and beds bearing salt water are penetrated before fresh water is reached.

To make absolute determination as to the most effective method of developing the water supplies of the actual Island would require much more detailed information as to the nature, extent and interconnection of the underlying strata than is now available or, in fact, than can ever be hoped for. This particularly applies to those parts of the strata which lie below the ocean and where exploration by well sinking is out of the question. It is, however, the safest, even though it may not be the most efficient, method to locate the wells inland as the ideal case above.

There is another advantage in doing this. Small wells can be put down near the shore and water from them tested from time to time for salinity, thus early warning of the encroachment of sea water can be obtained and remedial measures can be taken.

It is thought that if the maximum amount of water were to be taken from the Island, the development should be by lines of wells sunk on high ground and discharging into an aqueduct following the axis of the Island.

If the underlying material were uniform, the maximum development would be given by wells sunk as deep as salt water intrusion would justify. If the water-bearing beds were found to be completely isolated from each other by impervious strata, wells should be sunk to the various water-bearing horizons. Little is known of actual conditions, so it must be assumed that wells of various depths would be required.

Any such complete development would have to be under unified control and all other development prohibited. Otherwise some beds would be over-pumped and rendered saline.

There is no record of a water-bearing bed that has once become heavily salted again becoming a serviceable source of supply for fresh water. Doubtless it could happen, but the rate of flow through the ground is small and the time required to wash these beds free from salt is undoubtedly long.

It is certain that inflow of salt water can be prevented only by so regulating pumpage that even with the pumps running, the lowering of the hydraulic gradient will not be sufficient to upset the hydrostatic balance between salt and fresh water. In theory this would require the water level even during pumping to be kept higher than an elevation above tide equal to one-fortieth of the depth of rock below sea level at the site of the well. Such rule may be impossible to follow in practice, but if violated it should be with full knowledge that adverse and probable cumulative effects will result. These might be large or too minute to be meas-

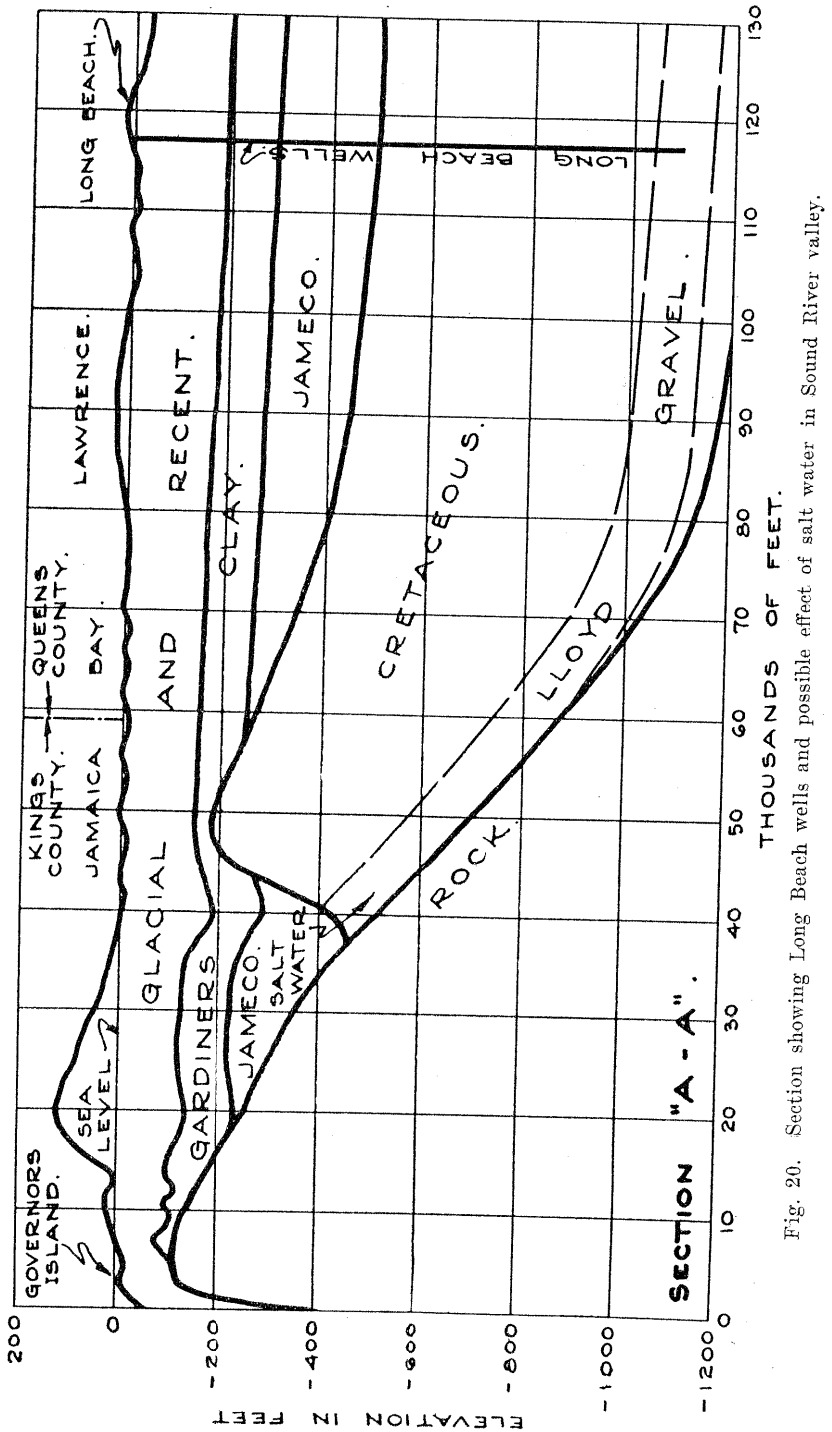


Fig. 20. Section showing Long Beach wells and possible effect of salt water in Sound River valley.

ured. This also points to a location for the wells at the highest obtainable ground water level, providing the rock is not too near the surface.

Water Supply of the City of New York

New York City always has been and will continue to be the largest single water consumer on the island. In fact, it consumes more Long Island water than all the rest of the Island at the present time. Therefore, the water supply questions of city and island must always be considered together and it is essentially true that Nassau and Suffolk counties are more vitally affected by the question of where and when New York City develops an additional supply of water than are the upstate counties from which the new supply may be taken.

Until the year 1917 when water from Ashokan reservoir first reached Long Island, the water works system of the greater city was divided into three distinct parts.

Manhattan long ago obtained a gravity supply of water from Croton river. Bronx was partly supplied from Rye pond. These parts were combined, reinforced by water from Byram river and finally by that of Esopus creek and Schoharie kill, brought down by Catskill aqueduct.

Richmond had its own local sources of supply and obtained a certain amount of water from New Jersey. The Jersey supply was cut off by legislation and eventually Catskill water was carried from Manhattan, through Brooklyn, across the Narrows on to Staten Island.

Brooklyn and Queens long had to depend on Long Island sources. The Brooklyn supply and several small municipal plants were interconnected and merged into one when the Catskill mains were extended under East river and out into the Long Island boroughs. Large areas in both boroughs were and still are supplied by private enterprise, but the city has acquired the plants of Citizens' Water Supply Company of Newtown, Long Island Water Company and others within its limits. Three large private plants remain.

The accompanying diagrams show pumping to supply the people of the city and also the amount of water supplied on Long Island through the Catskill works. Another diagram shows the growth of population, use of water and available supplies for the city. The accompanying map shows the sources of supply now in use for the people of the city of New York (public, private and industrial), as well as the proposed Rondout and Delaware-Rondout projects.

It is evident that the presence of the water companies, unless the city cooperates with them more than it has done in the past, adds to the complications. Thus before Catskill aqueduct came into service the city as a whole was short of water and the Long Island section even more so. As soon as Catskill water was avail-

able the city had more gravity water than it needed to supply all the boroughs and it cost practically no more to run the aqueduct at full capacity than at a lesser figure. True economic considerations would have required complete cessation of well pumping from Long Island wells supplying the city. The city did shut down most of its plants for a few years, but the companies were not supplied with Catskill water and so continued to pump ground water. In some sections the city found it cheaper to pump water than to construct the larger mains required to supply them by

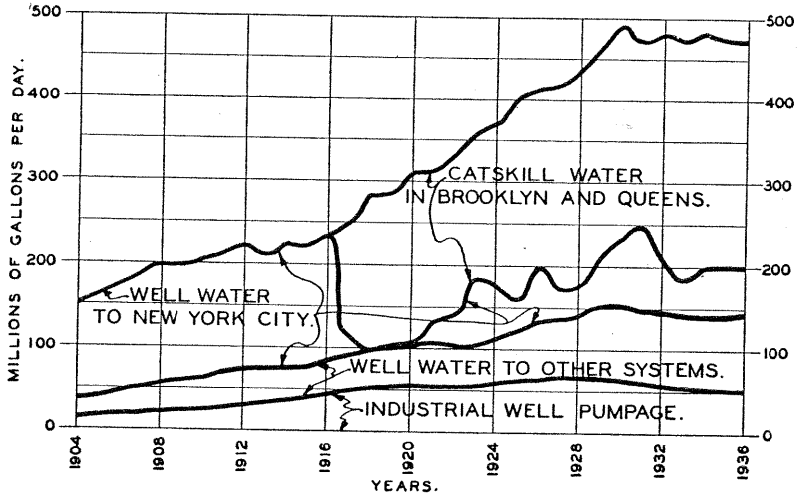


Fig. 21. Water used on Long Island.

gravity. Had all pumping ceased during the period when enough Catskill water was available, a reasonable percentage of the overdraft on the Long Island beds would not have occurred. Even today there are times when the city's gravity supply is running to waste and that wasted water could be used to reduce the overpumping in Brooklyn.

Finally the depression stressed economy and the city increased its water rates, resulting in a great stimulus to industrial pumping. There is a very considerable financial argument for pumping well water at $25.00 a million gallons in lieu of buying the water from the city at $200.00 a million gallons and the plant owners did not and could not be expected to know, or much to concern themselves, with the fact that by such action the water supply sources of the west end of the Island were being destroyed and the financial advantage could not be more than temporary.

When Schoharie tunnel was opened in 1924, it was known that prudence required New York City at once to start construction on another large addition to its water supply system. Had this been done Delaware water would now be flowing into all boroughs of

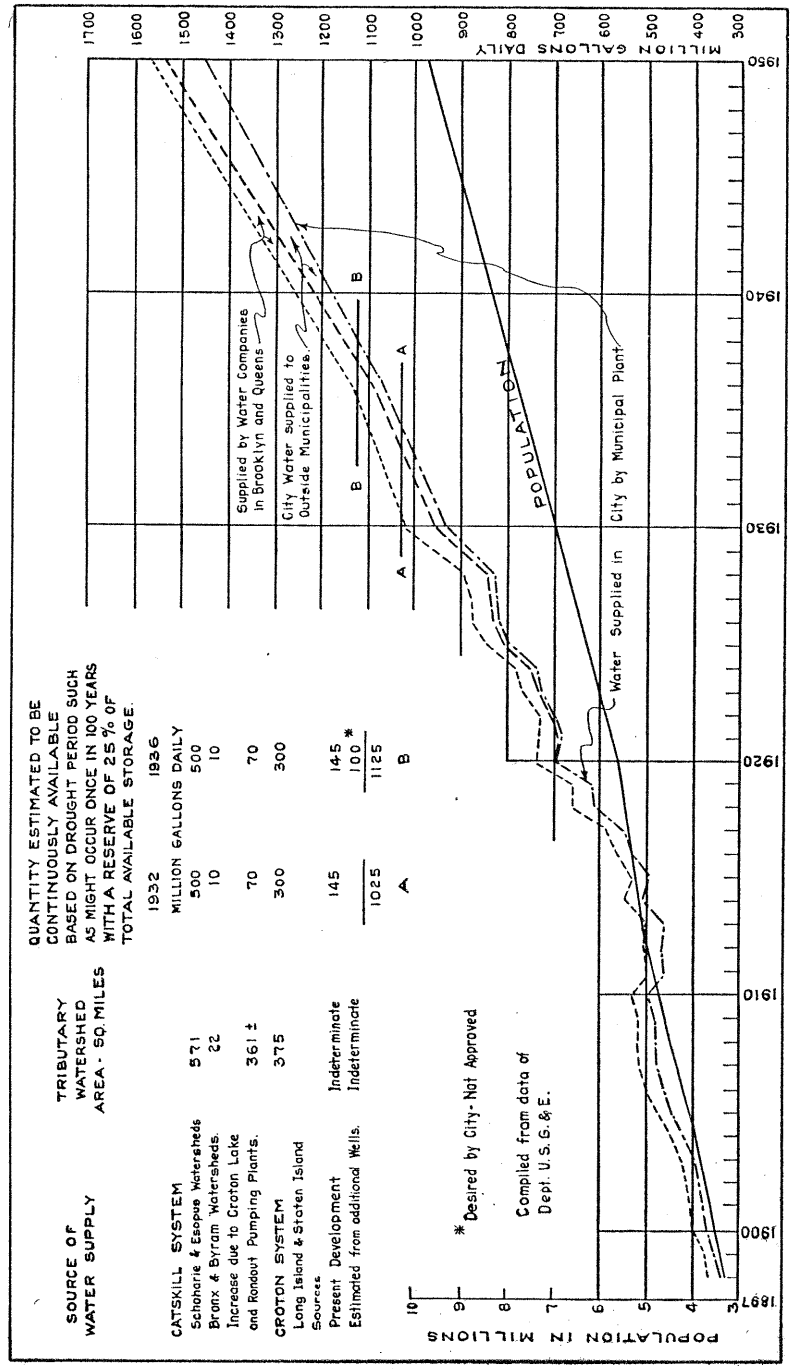


Fig. 22. Time curves showing population and demand for water in New York City and available safe supply.

the city in excess of their needs and there would be no need for further city pumping for some years. For various reasons starting of a new project was delayed and now a water shortage seems imminent. Such shortage would be bad enough for the city, but it bids fair also to have evil effects on Nassau and Suffolk counties, which occupy in part the role of innocent bystanders. Only in part, as in Nassau and to a lesser degree in Suffolk, these counties and the city share population, social and commercial interests.

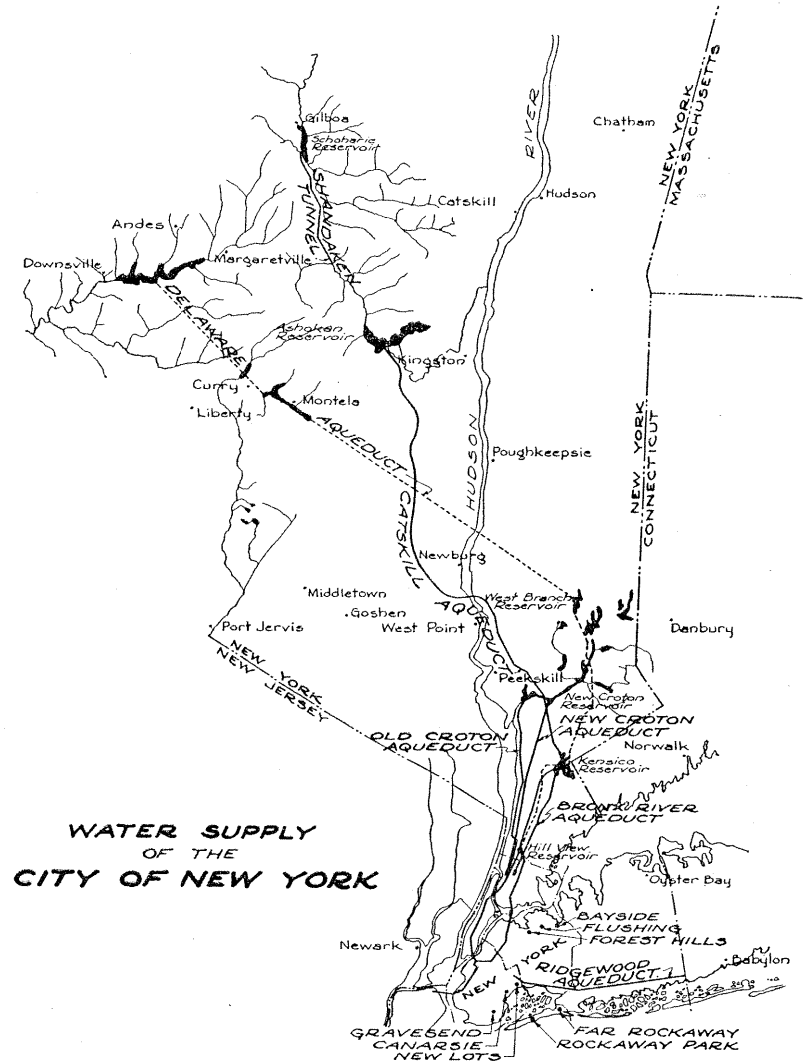


Fig. 23. Sources of water supply used by the City of New York—municipal system.

Changes in Ground Water Levels

In 1905 the water problems of the city were given elaborate study and the conditions on Long Island were investigated in detail, mapped and reported on by the United States Geological Survey and a commission acting for the city (the so-called Burr-

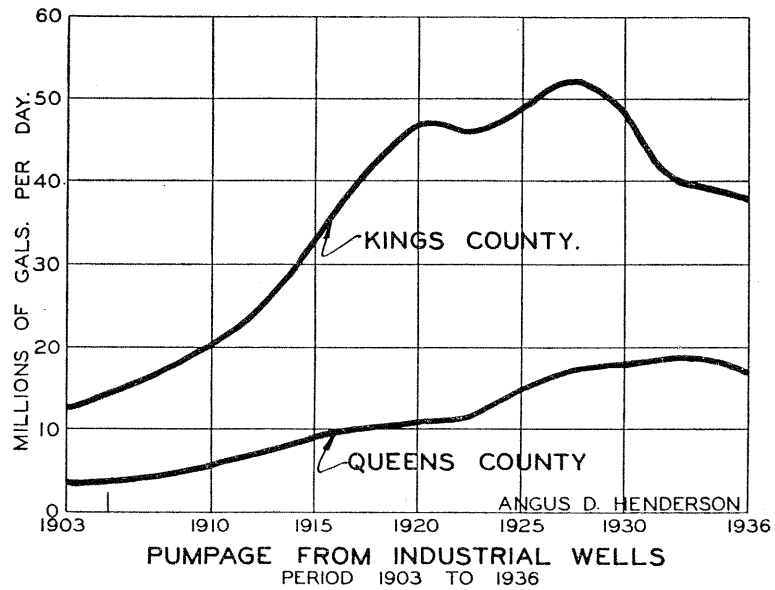


Fig. 24. Industrial pumping in Kings and Queens Counties.

Hering-Freeman Commission). Among other things the contours of the upper ground water surface of part of the Island were mapped and this information is here reproduced. These contours did not extend over Brooklyn, but they have been so extended by Thomas H. Wiggin, Consulting Engineer, of New York and former Principal Designing Engineer of the Board of Water Supply of the City of New York.

Later and prior to 1911 this study was continued and reported on by the Board of Water Supply. In that year the Board recommended the development of additional water supplies from Suffolk county. This report was adopted by the city and application for approval of the project was made to the State Water Supply Commission, but was finally dropped, partly at least, on account of the opposition of Suffolk county and partly because it was decided to develop Schoharie kill instead.

In 1933 New York made application to the Water Power and Control Commission for authority to develop additional supplies in Kings, Queens and Nassau counties. This application was based

on the assumption that the ground water contours at that time were the same as they had been in 1903. The application was opposed by Nassau county and by many municipalities and water companies.

During the course of those proceedings the writer advised the Commission that the city was proceeding on the above assumption, stated that there was no proof at all of the existing conditions and recommended that evidence showing present conditions be called for. The Commission accepted this recommendation and the engineers of the city and opposing companies made a joint investigation and submitted a map showing the existing water levels. That map is not here reproduced, but it is somewhat similar to the map showing ground water contours in 1936, except that it covered only the city area and there have been changes for the worse in the intervening years.

This joint map showed that there had been tremendous and unsuspected changes in thirty years. Further studies were made by the engineers and the situation developed. It has been ably reported by William F. Laase, Borough Engineer for Queens of the Department of Water Supply, Gas and Electricity of the city. It has also been described by the Commission in various decisions and by the writer in his report of March 20, 1934, on the applications then under consideration. This last report has not been published but has been printed in the record on appeal in a number of certiorari cases. Briefly the following was found.

Ground water resources in Brooklyn had been greatly reduced in productivity by sewers, drains, paved streets, etc., cutting the replenishment of the strata by intercepting the rainfall and running it into salt water. Pumping in that county had been carried on at about 60 to 70 millions of gallons daily, far in excess of the safe yield. Practically everywhere in that county the ground water level had been lowered below sea level. In the heart of Brooklyn it was 20 feet below that level, even when the pumps are not running. Such reduction in level had caused sea water to flow into the beds, diminishing the value of the water in them and still further reducing the safe yield of potable water. Only a relatively small area in the county could still be used as a source of fresh water. These effects were continuing and still continue, although the rate of increase has been somewhat reduced.

In Queens the rate of draft as a whole did not exceed, but was near the safe yield. There were local overdrafts, notably along the south shore by city stations and Woodhaven plant of New York Water Service Corporation. Tremendous lowering of the ground water table in Kings had also lowered that table all over Queens and the configuration was such as to show that the body of ground water in Queens was, except as intercepted by local pumps, flowing towards Kings.

All along the Queens-Nassau county line this Brooklyn overdraft had lowered the ground water level by many feet. How far

Fig. 26 — Upper ground water surface on Long Island in 1936.

Fig. 25 — Upper ground water surface on Long Island in 1903.

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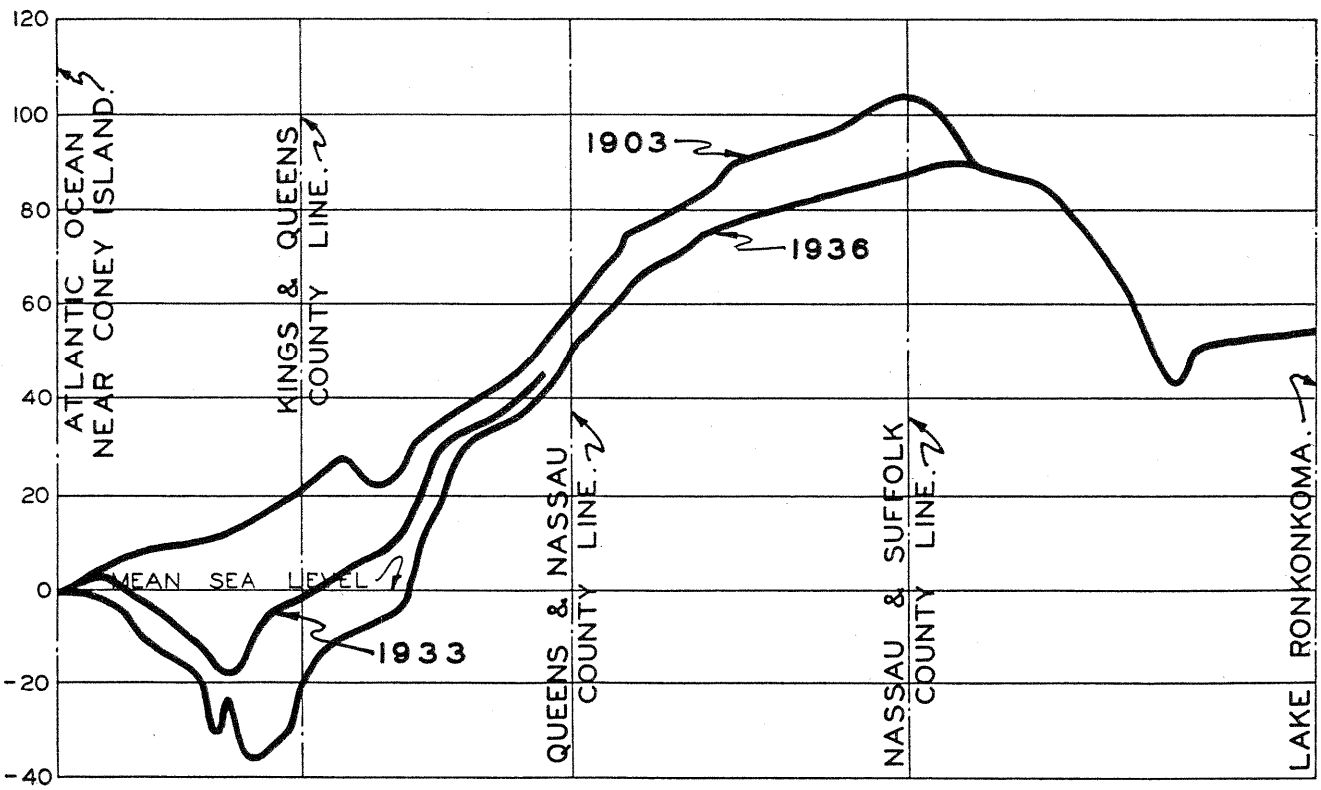

Fig. 27. Section of Long Island showing surface of ground water in 1903, 1933 and 1936.

into Nassau county that effect went and whether it extended to Suffolk was not then (1933) known. That has been a matter of particular study in preparing this report and the conditions are here shown by profiles and cuts.

All these facts are better shown by models that have been constructed than can be done by maps and diagrams. The models cannot be reproduced here but photographs of them are included for what use can be made of them. They are somewhat disappointing.

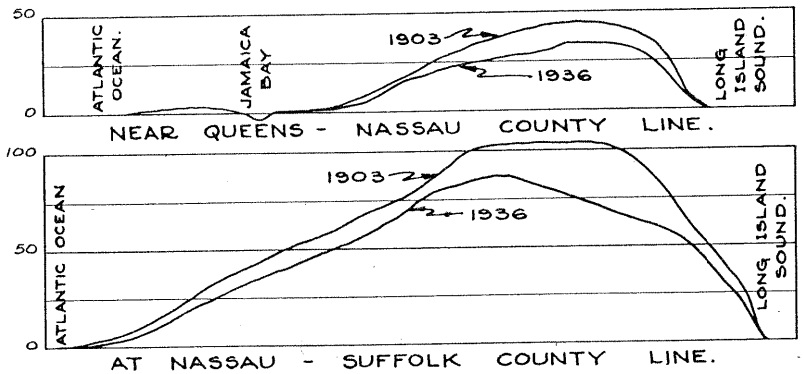

Fig. 28. Sections of Long Island showing surface of ground water in 1903 and 1936.

Latest information shows material changes for the worse in the period 1933-1936. Not only has the Brooklyn depression gone down — as was expected — but the depressed area has extended far to the east into Queens county. The effects in Nassau county are serious and there can be no doubt but that they extend even into Suffolk, although somewhat masked by the difficulty of avoiding perched water tables in the ranges of hills near the county line.

It is thought that the steepness of the ground water slope in Queens is due to the effect of the underground stratification, follows somewhat the eastern wall of "Sound River Valley," so-called, and may not be truly shown by the contours.

Great recession in ground water levels is shown along the Flushing bay — Woodhaven line, which is not only disquieting at best, but most serious in view of the probable demands for water when the World's Fair is built in this region.

Great accuracy cannot be obtained in such studies. In a heavily pumped area the ground water level fluctuates greatly with the operation of the pumps. These maps are supposed to be based on the level when there is no pumping, a condition which may not occur. There is always a probability that they will be lower than they should be. On the other hand, if levels were taken during

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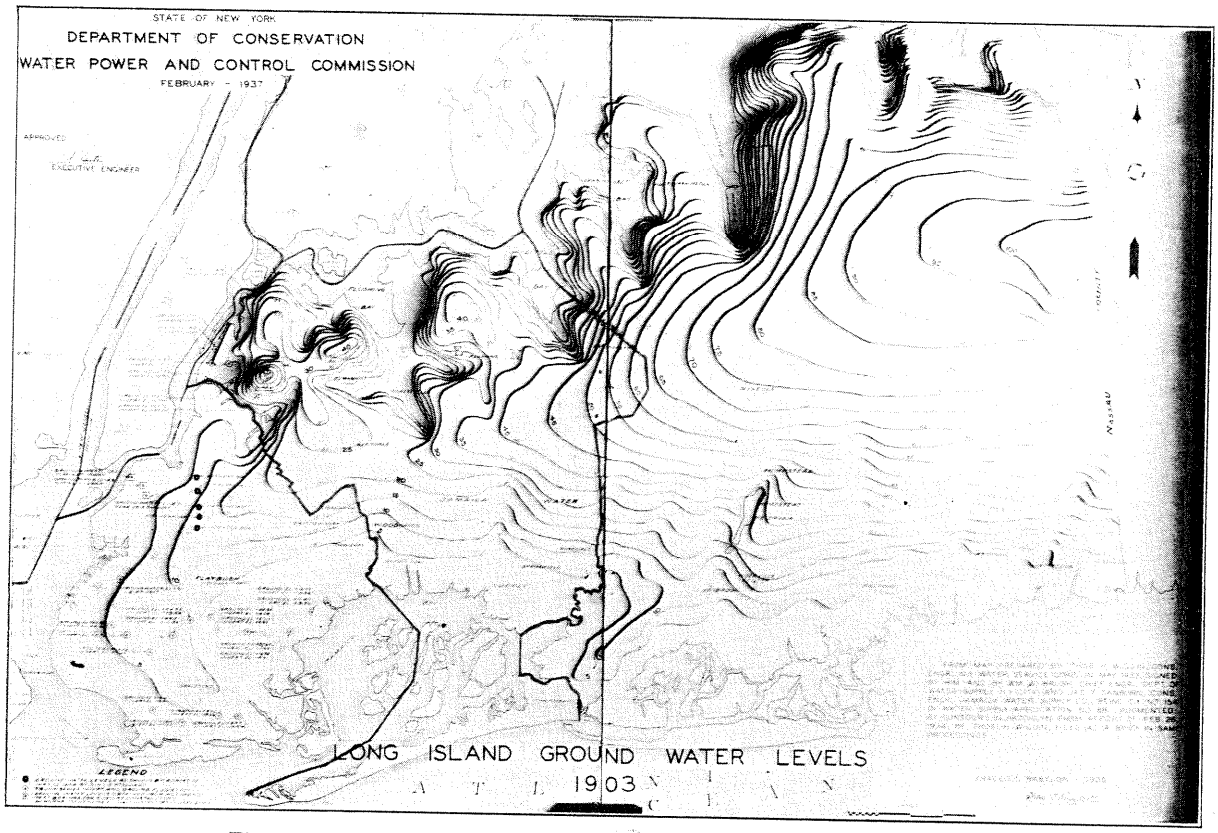

Fig. 29. Model of upper ground water surface on Long Island in 1903

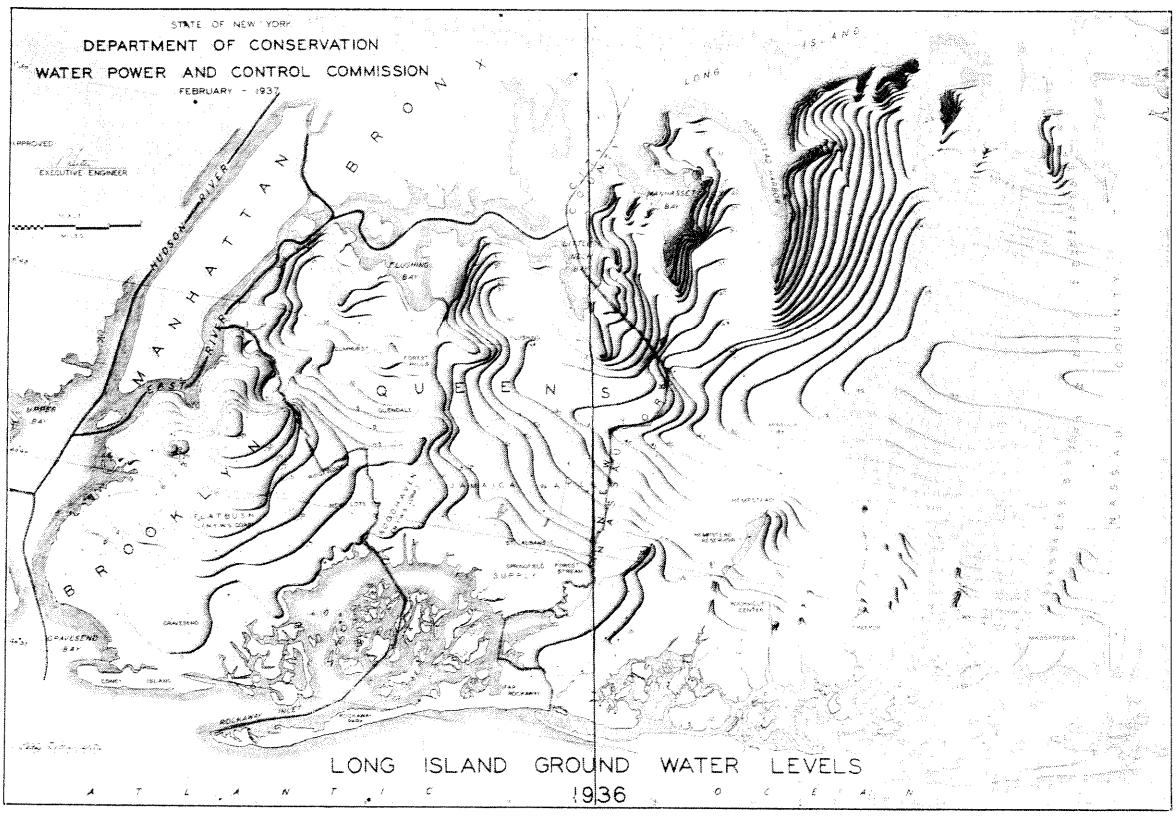

Fig. 30. Model of upper ground water surface on Long Island in 1936

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periods of maximum pumping, they would show the ground water surface at a materially lower elevation. These fluctuations in level also affect the inflow of salt water.

There is ever present danger that in hills, along the moraines and in disturbed strata generally levels may be taken in wells piercing "perched" water deposits and so fail to indicate the true upper surface of the main body of ground water.

As the Cretaceous strata slope to the southeast and the observations, particularly along the north shore, may be taken in different strata, there is a possibility that the ground water surface may not actually be continuous.

Measurements are lacking in precision. In many cases the elevations of the tops of the wells are known only roughly, or are estimated from the topographic maps.

In addition to all this there is a fluctuation of the ground water surface due to variations in the rainfall. This has a tendency to swing through long periods of years, following the excess and deficiency of the total rainfall over or under the average, as shown by the cumulative rainfall diagram.

This last effect may amount to eight to ten feet to judge by the history of the fluctuations in the level of Lake Ronkonkoma. This could happen only at the highest points along the axis of the island. Near the shore the elevation of the upper ground water surface is fixed at sea level.

Such changes in level would not alter the general form of the surface, they would merely raise or lower the summit of the ridge. They could not cause the depressions or abnormal changes shown in Kings and Queens.

Were pumping stopped there would be marked changes for some years, as the water would continue to flow to the depressions until they were filled up and a more nearly normal configuration restored.

Geology of Western End of Long Island

Although throughout the greater part of the island the deeper strata, as far as known, are quite regular, there is a section under Kings and Queens counties which differs markedly from the normal arrangement. It happens that in this section there is the greatest concentration of pumping, so the underground conditions are of unusual importance. With this in mind the services of J. Homer Sanford, Engineer, Geologist and practical Well Driller, were engaged and he has made an intensive study of this area. The object was to obtain practical information which would serve to guide well development rather than to write a scientific geological report. It is interesting to note that in spite of the tremendous amount of well drilling that has been done in this area the data now obtainable are too few to permit a reasonably accurate determination of many important points. A few test wells at strategic locations would be most valuable.

Prior to the ice age the depression of Long Island Sound extended across Queens and Brooklyn to the Hudson. The rock outcrop along what is now East river forced this depression over to the southeast. Some geologists believe that this depression was a true extension of the Sound and that once, during a period when the land was at a considerably higher elevation above sea level than at present, Connecticut river ran westerly through the Sound and its continuation to reach the Hudson somewhere off Rockaway beach. This theory was based on the known existence of the so-called Sound River valley under Brooklyn and partly on analogy with the courses of the Delaware, Susquehanna and other streams which turn sharply to the right on reaching the line of contact between the Cretaceous peneplain and the coastal plain.

Such determination of the top of the Cretaceous strata in this region as has been possible suggests that no valley large enough to carry the Connecticut could have existed and that the depression might better be known as the pre-glacial valley of the Bronx. The pre-glacial gorge of the Hudson is supposed to be many hundreds of feet deep and to be largely in rock at this point. Had a stream of the magnitude of the Connecticut entered this gorge as supposed, it must have cut a deep notch in the side of the gorge and there should now exist in the rock a side canyon under Coney Island with perhaps a waterfall around the neighborhood of Flatbush. No evidence of such formation has been found and such pre-glacial valley as is known is neither low enough or large enough to have carried that river. Nevertheless, there is such a valley and it appears at one time to have carried a vast amount of gravel and debris.

It is possible that the valley originally existing has been considerably deformed by ice. No current explanation of the formation of Long Island Sound is quite convincing, but it is probable at least that it was but partly eroded and was enlarged and the steep southerly escarpment formed by "bulldozing" action of the ice sheet as it crossed the Sound. The bays of the north shore and that of Newtown creek probably might be classed as glacial scratches, gouged out of the original island by the heavy ice sheet riding up the northerly slope.

According to the best information available, the axis of this depression ran from somewhere near the foot of Little Neck bay under East New York to Coney Island. In places, particularly at the lower end, this valley cut down through the Cretaceous sediments to the rock, but at the upper end it did not go deeper than the Lloyd gravel. Cretaceous deposits remain north and west of it in Queens and in the Newtown creek—Gowanus canal region of Brooklyn. In general the southeasterly wall of this valley was a steep escarpment in Cretaceous sediments. Near the Hudson gorge there seems to have been an enlargement over which the softer sediments have been cleaned off down to the rock. This may have been a pot hole effect produced by the Hudson after the deeper parts of the rock gorge of that stream had been submerged and filled up.

Fig. 31 — Rock contours under Kings and Queens.

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Prior to the ice age the land was elevated, perhaps even to the extent that the entire continental shelf and the seaward escarpment bounding it were above water. As the ice approached from the north, the weight of the ice sheet forced the ground down and it is supposed that the whole of Long Island was submerged when the ice rode over it. During the period of sinking the valleys and depressions in the Cretaceous land surface were largely filled with material loosened and transported by the ice and carried ahead of it by the flashy streams originating along the ice front. The character of these deposits varied with the proximity of the ice front.

While the ice was somewhat remote, standing somewhere in Connecticut and southern New York, this outwash was a characteristic gravel and sand usually known as "Jameco". It is one of the best known water-bearing formations of the island and was considerably developed by the old city of Brooklyn wells. The lower filling of the deeper part of Sound River valley consists of this material.

Continued depression and submergence of the Sound, which tended to cut off the supply of Jameco material, caused the nature of the deposit in this valley to change to clay (Gardiner's clay — also called Sankaty). Probably this clay was laid down in a bay behind a barrier beach, a formation somewhat similar to the bays along the south shore at the present time. This deposit was formed progressively as the island continued to sink so that it is not level but inclines to the south. Over this there are found deposits of sands and gravels. In those portions earliest submerged there are beach sands, the bar beach itself. Later glacial outwash came from the ice sheet as the Sound became filled up. This deposit merged with ground moraine (Montauk till) as the ice sheet passed over the island and out to sea, succeeded by outwash gravels as it retreated once more to the north. Here Mr. Sanford assumes an interglacial period (Vineyard) intervened during which there was erosion of the recently deposited materials. This was followed by the advance of the Wisconsin ice sheet which added the terminal moraines and surface glaciation now so conspicuous on Long Island.

In Brooklyn today the main water-bearing horizons lie immediately above and below the Gardiner's clay. Most of the industrial wells are in the upper stratum. A few go down to the Jameco formations underneath. The water wells in Flatbush draw water both from above and below the Gardiner's horizon. These valley fillings generally are more porous than the older sediments and the peculiar shape of the ground water surface in Brooklyn probably is due to these variations in porosity. Thus the greatest depression in the ground water surface is west of the valley where there are Cretaceous deposits on the rock. Flatbush wells are all in the valley filling, which may account for the small effect they have on the shape of the ground water depression as compared with the industrial wells further north.

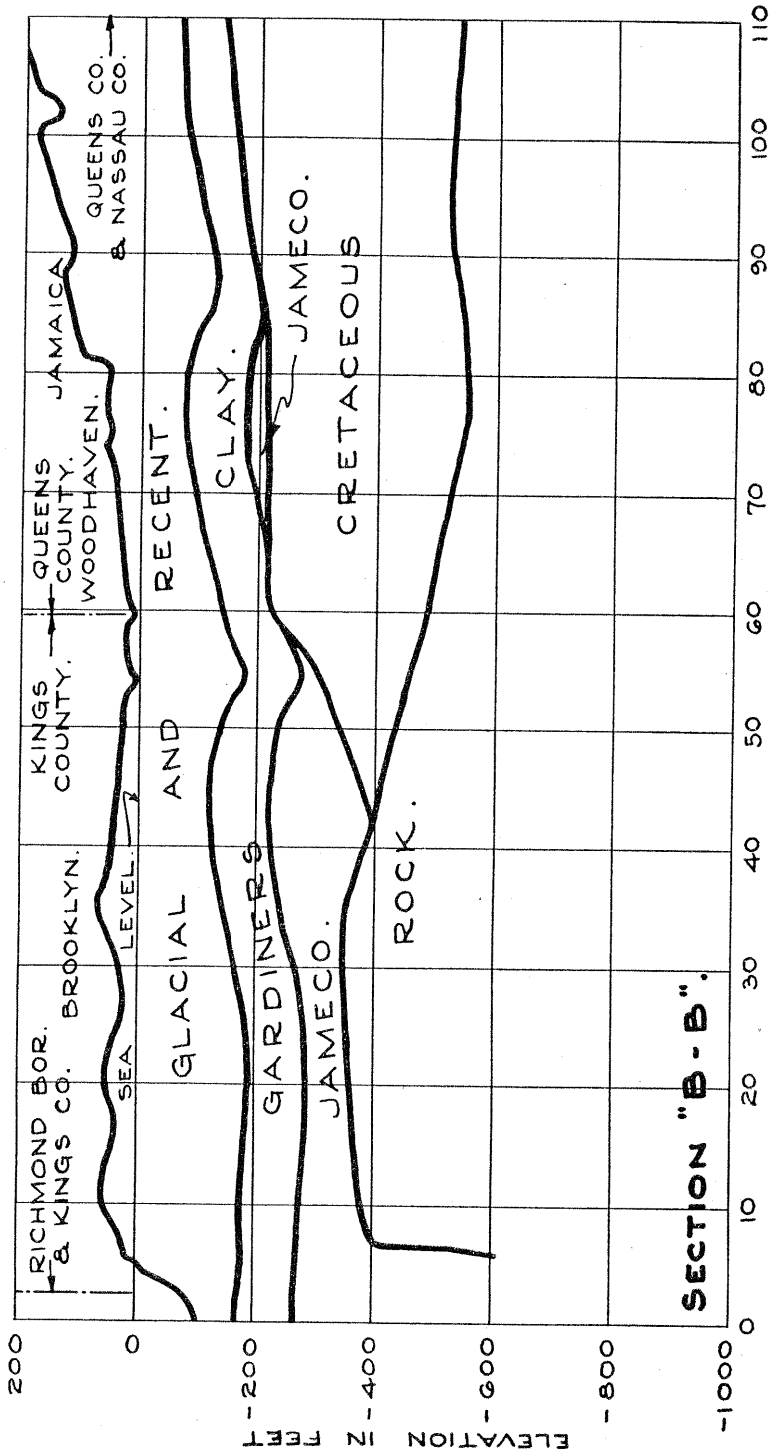

Fig. 34. Section on axis of Sound River valley.

Over-pumping of ground water is filling Sound River valley with salt water. Not only is this destroying the value of the beds supplying Brooklyn, but it constitutes a serious menace to supplies in Queens and Nassau counties drawn from the Lloyd gravels. This particular formation generally over the island is the lowest of the Cretaceous strata, resting either directly on the rock or on decomposed rock. Wherever it can be reached further east on the island, it is extensively used and is highly regarded on account of the superior quality of the water from it. This formation is cut by and floors a portion of Sound River valley. It slopes off to the southeast. Over it nearly everywhere is a heavy bed of clay so that there has always been much speculation as to the source of the water in these gravels. One theory is that this water all comes from Sound River valley. Should that be true, it would follow that the salting of the beds in Brooklyn would be followed by the

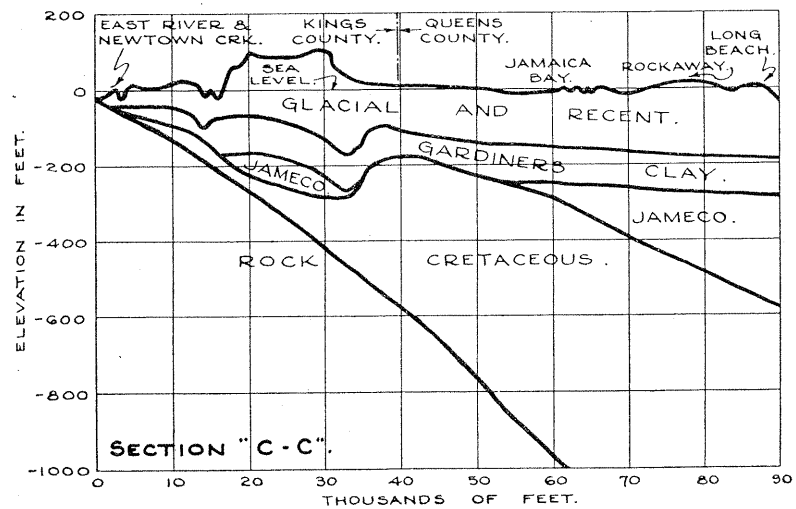

Fig. 35. Section across Sound River valley.

salting of the Lloyds to the east. This constitutes an immediate menace to the water supply of Long Beach and other places. Whatever may be the origin of the water in the Lloyds, it has been seriously depleted in New York City and in many places the present static water level in these beds is now below sea level (Fig. 20).

Air-Conditioning

Advances in civilization and changes in the living habits of the people may greatly upset long established ideas and nullify over night the best estimate of future trends. The municipal water supplies of the country have recently been hit in this way and all such plants are now faced with the most serious problems. The invention, development and widespread use of air-conditioning is

causing serious alarm among the water works officials of all municipalities. These devices all use more or less water and practically all of them must obtain that water from the public mains and sources of supply. Should air-conditioning be extended generally to the houses of the people, either some method of operation which will not require water must be developed and insisted upon or all public water supply systems must seek large increments to their supplies of water and greatly enlarge their plants. In addition, a heavy additional load will be thrown on all sewerage systems and sewage disposal plants which handle this extra water.

During the years 1934 to 1936 in Brooklyn and Queens the Commission was called upon to act on applications for several hundred wells to be sunk for air-conditioning theatres, restaurants, stores and public buildings, requiring six billion gallons yearly with a possible maximum rated pumpage of 84 million gallons daily. Those boroughs are fortunate in that not only can the required water at low temperature be cheaply obtained from wells in the buildings themselves, but the water after use and only with a somewhat higher temperature readily can be diffused back into the ground. By so doing not only is the load on the public mains relieved but the ground water is but little, if any, disturbed. This problem is not yet so distressing on Long Island as elsewhere, but universal household use could not so readily be handled.

Regulatory Legislation

By Chapter 563, Laws of 1933, the Legislature took cognizance of the Long Island situation, declared conditions to constitute an emergency and required the consent of the Commission prior to the sinking of any well, other than an agricultural well, on Long Island if the capacity of that well should be in excess of 100,000 gallons daily (69.44 gallons per minute). This Law has been amended by Chapter 381, Laws of 1934, and Chapter 517, Laws of 1935. To facilitate the administration of that Law, by Chapter 338, Laws of 1935, it was required that no well driller could operate on the Island without a license from the Commission and without making certain reports to it.

These laws have enabled the Commission to prevent the sinking of many wells in the areas where the present rates of pumping are excessive. No power has been given the Commission to stop pumping from wells installed prior to the enactment of the law and, of course, many small wells outside the jurisdiction of the Commission have been put down. The net effect has been to reduce the rate of increase in the amount of pumping, but not to reduce the amount.

The Commission has no authority over the equally destructive operations, as far as ground water is concerned, of the construction of sewers, storm drains and similar works which by intercepting rain before it enters the ground, reduce the recharge and so the safe yield of the ground water beds.

Enlarged powers would have to be granted the Commission before it could be asked to prevent further increase in pumping. To correct the situation which has grown up would require much more extensive and drastic powers.

Over-Pumping of Ground Water

Unrestricted sinking of and pumping from wells on Long Island has already destroyed a large part of the value of the water-bearing beds underlying Brooklyn. This condition has not been checked by recent legislation and is growing worse. This over-pumping in Kings county has lowered the ground water levels in Queens and Nassau counties and even in western Suffolk county. If the ground water resources of the Island are to be preserved, it will be necessary to restore the ground water levels in Kings to a point where salt water intrusion will cease, cautiously resume pumping in Kings at a rate consistent with the preservation of that condition and to develop the ground water resources of the remainder of the Island in an intelligent and pre-planned manner as so to avoid producing in them the conditions now present in Kings. Physically all these things can be done, although more knowledge must be had as to underground stratification and the interconnection between the various water-bearing beds before the last step can be taken in confidence. There are several serious practical economic and legal questions which cannot be answered here.

Were it possible to start *de novo* with the Island in its original condition, the problem would be greatly simplified.

If New York City had an abundant supply of water, over-pumping could be stopped with less outcry, but the city is actually on the verge of a water shortage.

The presence of privately owned systems within the limits of the city, and to a lesser extent elsewhere, adds to the complications as water corporations and the municipalities they serve are too often at odds.

To refill the Brooklyn depression, withdrawal of ground water in that county must be stopped. This would mean the cessation of all pumping except where the water is diffused back into the ground. If the city supplied the whole area and had a liberal supply of water, this might be effected without undue economic hardship by making a special rate to plants that would give up well pumping and by forbidding the discharge of condenser and cooling water into the sewers.

It is reported that a large part of the present industrial pumping is of water for cooling and condensing. For these purposes the low temperature of the ground water makes it of exceptional value. The processes themselves tend to raise the temperature of the water but in general do not pollute it. By returning all such water to the ground not only would the lowering of the water table by such pumping be prevented, but a material load would be

taken off the sewerage system and present and future sewage treatment works. It would seem that this might be a matter within the powers of the city and worthy of careful consideration by the city authorities.

Even now there are times when the city is letting water run to waste and during such periods it would be economically advantageous for it to sell such surplus water at favorable rates to replace the water which otherwise would be pumped from the ground.

For cooling and condensing, water which is too saline for drinking purposes can be used. Such water, however, should not be discharged outboard of the Island as by so doing the water table will be depressed still further, salting of strata increased and other areas affected. Even though nothing but salt water were available in Brooklyn, it would still be essential to fill up the ground water depression in order to save the supplies in other counties.

At the moment industrial pumping is lower than it has been for some years, but renewed prosperity may send it promptly to new heights with almost immediate destructive effects.

How much longer the Flatbush plant of New York Water Service Corporation can continue to operate on water drawn from wells in that area is problematical, but it cannot be for a long period. It is not clear that the company can by its own efforts obtain an additional supply elsewhere. Should its wells go salt, it may well be that the city will have to take on the burden of supplying the water required to the present customers of the company. From the physical standpoint it would be better for it to do so at once up to the limit of its available resources, thereby helping to restore the Brooklyn levels.

Redevelopment after the restoration of proper water levels would have to be carried out under most drastic control or it would fail of its object.

General development of the remaining resources of the Island could most effectively be brought about by large scale projects under public control and by stopping all pumping not in conformity with such general scheme.

All these things can be done as far as physical conditions are concerned, but they cannot be started until certain legal matters are cleared up.

Property Rights and Legal Considerations

An engineering report is not the place to settle or even to discuss questions of law, but it is proper and suitable in such a report to point out the matters requiring elucidation and the powers which are necessary to bring about desired results.

Up to now the users of ground water have proceeded on the assumption that by right of ownership of a parcel of land the owner or occupier has the right to put down wells and to pump water from them to the limit of their capacity. It is abundantly evident that such practice cannot go on indefinitely, as the total

amount of fresh water available is strictly limited. Therefore, it is inevitable that at some point the legal rights of the persons desiring so to develop wells must be defined. That time has now arrived on Long Island.

The situation most nearly analogous to this is that of oil wells, but there is an important and perhaps vital difference. Oil exists only in limited quantities. When once used it is gone and cannot be replaced. The great value of ground water is that within limits it replaces itself and, therefore, can be pumped forever.

As far as water is concerned there are two obvious solutions. It may be held that the first appropriator of water has obtained a legal right to the amount he has developed; in which case development by others which would adversely affect him would have to be prevented. All land owners might be held to have equal rights to take water; in which case, if all land owners availed themselves of this right, none could pump more water than originates on his land. This is an amount which can be determined with some degree of accuracy. It has been estimated that each square mile of island surface in its original condition can produce a little better than a million gallons daily. This amount would be less if by drains, sewers and other construction the rainfall were diverted from the ground to the ocean. Putting this in more understandable terms, the owner of a standard 25 foot by 100 foot building lot would be able to draw about 80 gallons a day.

Administrative details would be most difficult if fairly complete development took place. This is the condition which exists today in Brooklyn.

There arises the further question of the right of the municipalities and the water companies serving them to take water from the ground under the property of others and without compensation or condemnation.

The only practical solution is by drastic regulation by governmental authority. This can be planned only after determination of what vested rights, if any, exist to continue to pump water from long established wells.

If the State or lesser authority has the power to take over the whole situation and to stop over-pumping at one point and direct pumping at another, the problem of regulation becomes one of engineering and can be worked out.

The Problem of Regulation

Even though the water-bearing beds under parts of the Island are now over-pumped, the ground water resources of the Island as a whole are greatly under-developed. The engineering solution involves the sinking of wells in unexploited territory and the transportation of the water from such areas to those where pumping has to be curtailed. Proper regulation can be had only if the ultimate regulating authority has powers not only island-wide, but extending over the water supply of New York City. This means State authority. It must be emphasized that the counties cannot

control the situation. The water-bearing beds of the Island are to a considerable degree interconnected and it is not only possible but is now happening that the wells in one county can draw water through the ground under the county boundaries. Except for such regulatory powers as the Commission now has, it would be easy for either Nassau or Suffolk counties to put down a line of wells just inside the county line and pump from them large volumes of water, at least one-half of which would come from the other county. Kings county now is supplied with water from Queens, Nassau and Suffolk counties transported through the underlying strata. No local restrictive law can prevent this and the present powers of the Commission are insufficient. The obvious procedure would be for the State to assume the necessary additional powers.

When it comes to actual development, several methods may be followed. The present plan is to permit individual development by the various municipalities, corporations and individuals subject to the control of the Commission. This now is inadequate and, at least outside of Suffolk county, a more comprehensive scheme is needed. It is suggested that actual development, construction and operation of comprehensive water supply systems might be left to the city and the two outside counties, under the general control of the State. That control, however, would need to be more complete than at present, as supplying of water across county lines where needed must be contemplated and provided for.

There are now many millions of gallons of water running to waste from Nassau county and many hundreds of millions of gallons so being wasted from Suffolk county. The circumstances of the case are such that the prior right of these two counties to use this water, if needed, should be safeguarded, they can go nowhere else for water, but the general good of the people of the State may require the use of that water elsewhere than in the particular county in which it originates up to the time when the county really needs the water itself.

The most favorable solution would be for each county to develop its water supply resources up to the point, under such limit as may be set by the State, where the water is salable to less favored sections. By so doing the necessary works will be in place and in considerable measure paid for by the time the county needs them for its own purposes.

All this is based on the assumption that the State will not allow and can prevent development in excess of the safe yield. Up to that point the water now wasted can be used to economic advantage and without detriment to the water supply resources of the area in question.

Today New York City could use additional Long Island water. There is a strong probability that it must use such water to avoid actual water shortage prior to the time when Delaware water will be available. Later on it is probable that Nassau county may need Suffolk county water. All this should be provided for.

There are advantages in having counties and subdivisions of the counties share in the control of this situation. The authorities of

such subdivisions are nearer to and better informed as to what is being done in a given area than is a State Commission in Albany and, most important, has the local police force to enforce the regulations of the Commission.

Form of Control

Even for the powers now exercised by the Commission, the organization for the administration of the law is not the most favorable. At present the administrative work is concentrated in Albany and the personnel is insufficient. There would be advantages in doing this work in a properly equipped and staffed office on the Island itself where it could keep in close touch with the situation and be more accessible for consultation. That could be arranged without difficulty if the funds were available.

Not only is control needed, but effective control will require constant investigation and study. Knowledge as to conditions on the Island is lamentably meager and considerable time and expenditure of funds will be required to collect the basic data which is essential. In addition continuous observation on the effect of pumping must be carried on and periodic audits of ground water conditions made. The prevent adverse situation came about because no authority was charged with the duty or had the necessary means to keep advised of the situation. That should not be permitted to occur again.

Finances

Whatever powers are exercised by the State over this Long Island situation will require funds. The amount needed will depend on the control exercised. Long Island should foot the bill, as the benefits accrue to the Island and its people. The cost as compared with the number of wells and the amount of water pumped would be comparatively small and it should be possible to devise some form of taxation or assessment which would be sufficient and not burdensome.

There must be over two thousand important wells on the Island, the pumpage amounts to at least 90 billions of gallons in a year.

Plans for regulation are too hazy to permit of accurate determination of what it would cost, but $20,000 annually might be considered a fairly liberal figure for the more strictly regulatory functions.

Special installation and tests would have to have special provsions made for them. These might include:

Test wells
Water level recorders in wells
Stream flow stations
Salinity testing stations
Special studies and reports
Cost of special proceedings
Cooperative works
Services of special experts

Organization and Results Obtained

Headquarters for the field work for this report was opened in Babylon and Stacy S. Rumpeltin, Senior Building Construction Engineer, detailed to the work of the Commission by the Chief Engineer of the Department of Public Works, was placed in charge. The remaining personnel was taken from the civil service lists as needed.

This force accomplished a great deal in the limited time available to them, particularly in view of the fact that none of them had any previous familiarity with the problems under investigation.

Four principal projects were set up to be accomplished:

(a) Determination of the 1936 ground water levels
(b) Determination of the location of and statistics on wells
(c) Determination of amount of industrial pumpage
(d) Study of the geologic formations of the extreme western end of the Island.

Ground water levels, as found, are shown by a contour map and accompanying profiles. In addition models were made showing these contours as in 1903 and 1936 over the three western counties. This is the most vital information obtained, as it is the key to the whole situation. Many of these elevations were determined by us, but county and municipal officials, officers of the water companies, well drillers and individuals, contributed the greater part of the information.

Well statistics for Kings and Queens counties were collected, tabulated, plotted and digested by Angus D. Henderson, an engineer in the employ of the Department of Water Supply, Gas and Electricity of the City of New York. He was given leave in order to do this work. He has furnished us with an enormous amount of valuable data. There was insufficient time to carry this work over into the two remaining counties, but that must some time be done.

Industrial pumping of moment is confined to New York City. Mr. Henderson collected data as to this along with the other statistics on the city wells.

Study of the "Sound River Valley" section of the western end of Long Island was made by J. Homer Sanford, Engineer, Geologist and well driller. This portion of the Island is dissimilar to any other part known and in it are the majority of the wells. Further studies are needed here particularly of the salt content of the water. This work is being done by the United States Geological Survey, but has not yet been reported on.

General studies of the location and extent of the water-bearing beds, the beds separating them and of the source of the water in them could not be undertaken, but are badly needed. This is in the hands of the United States Geological Survey.

To a large extent the data gathered represents the work of others and to that extent this has been a species of community

effort. Originally it was based on exhibits and testimony introduced at water supply hearings. This has been augmented by the further work of the original investigators.

For information of value and many courtesies we are particularly indebted to: A. E. Howland, Chief Engineer, Long Island State Park Commission, Commissioner Joseph Goodman and Borough Engineer William F. Laase of the Department of Water Supply, Gas and Electricity of the City of New York, Chief Engineer Vernon S. Moon of the Board of Estimate of the City of New York, President A. W. Cuddeback and Consulting Engineer Thomas H. Wiggin of New York Water Service Corporation, Vice-President N. F. Fenn of South Bay Consolidated Water Company, Paul M. Kydd, President of Jamaica Water Supply Company, Roger M. Leggette of the United States Geological Survey, Kyle Forrest of the Office of the County Engineer of Nassau County, Professor Charles P. Berkey of Columbia University and others for the data collected for the "Rock Line" maps of New York City and many others. The well drillers have been particularly helpful, freely placing at our disposal their records of past operations.

The staff assembled for the work are particularly to be commended for faithful service, zeal and intelligent cooperation.

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(Flatbush Plant — Fourth Application)

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